A SIMULATION TOOL FOR EVALUATING POWER CONTROL SCHEMES IN DS-CDMA CELLULAR ENVIRONMENT

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Certificate

It is certified that the work contained in the thesis entitled **"A simulation tool for evaluating Power Control Schemes in a DS-CDMA cellular environment"**, by *Amit Sharma*, has been carried out under my supervision and that this work has not been submitted elsewhere for a degree.

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Amit Sharma

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Chapter 1

Introduction

1.1 Introduction

Mobile communications has undergone significant changes and experienced enormous growth since its inception around 1980. The first generation mobile systems, AMP-S,TACS, NMT etc., were analog systems. Today in addition to the analog system-s second generation macro and micro cellular digital systems have been introduced which offer higher spectrum efficiency , multiple data rate services and more advanced roaming than the first generation systems.

Now wireless communication researchers are exploiting for highly reliable and high capacity digital systems as the third generation of mobile communication.

The mobile radio channel imposes fundamental limitations on the performance of wireless communication systems Radio channels in cellular systems have transmission paths that can vary from simple line-of-sight to those that are severely obstructed by mountains, trees, buildings and other man-made obstructions Another challenge confronted by a mobile radio network is to maintain a connection and service quality independent of the mobility of the terminal. The speed of the motion influences the rate at which the signal level fades as a mobile terminal moves in space

1.2 Cellular Radio Networks

In the cellular radio networks, the radio channel is shared by multiple users The frequency spectrum can be multiplexed amongst the users in three basic ways giving rise to three fundamental multiple access techniques. In frequency division multiple access (FDMA), the frequency spectrum that is alloted for the wireless network is divided into a number of frequency bands. A user occupies one frequency band for

the time it needs to transmit information. When the time of occupancy of a frequency band is divided into slots, the access technique is called time division multiple access (TDMA). A user would then occupy the frequency band only in the time slots that are assigned to it The third type of multiple access is known as direct sequence code division multiple access (DS-CDMA), where each terminal is assigned a unique code consisting of a certain number of symbols called chips When a terminal needs to communicate, it transmits on the carrier frequency common to all users but modulates its information with its unique code sequence before transmission. There are also schemes that are hybrid of the three basic multiple access schemes mentioned above.

1.2.1 Radio Resource Management

In the cellular radio network the establishment and maintenance of the calls between the mobile and the base station(s) requires proper network resource allocation so that the assignment of the base station, call admission control, channel allocation (frequency in FDMA, time slot in TDMA, and code in CDMA), mobile and base station transmitted power control, and handoff management can be applied effectively and efficiently. Due to time and space varying nature of the system, radio resources have to adapt dynamically to the instantaneous channel conditions (shadowing, fading etc.) and traffic levels (governing mainly the interference).

1.2.2 General flow of Resource Management Sub-tasks

Radio resource management for a mobile is initiated when the mobile is trying to make a connection and ends when the connection is terminated. When a new call arrives in a service area, a base station with the strongest beacon signal is allocated (*Base Station Assignment*) An admission check is then performed on the new mobile(*Admission control*). If admitted, the base station allocates the uplink and downlink channel for communication (*Channel Allocation*) The conversation then begins with the specified uplink and downlink transmitter powers. The transmitter power is adjusted continuously as per the employed power control strategy (*Power Control*). During the call, the link quality is repetitively checked and if certain hand-off criteria are met, as specified by the hand-Off algorithm, a hand-off attempt is initiated (*Hand-off Management*)

1.3 Cellular Network Design : Issues involved

The issues that decide the feasibility and the technological as well as commercial viability are focussed upon in the section

1.3.1 Frequency Reuse

The system should have high spectral efficiency. The most important factor that has resulted in the initiation of commercial implementation is the concept of frequency reuse, where the same frequency band can be reused at spatially different locations

In case of TDMA and FDMA systems frequency reuse requires a certain minimum distance between the two cells, operating on same frequency band, which is governed by the amount of co-channel interference the system can tolerate In practical systems the typical value of reuse factor is 7 [16] i.e. the same frequency band can only be reused in one cell in a cluster of seven cells Alongwith this limitation a slotted system [1] requires that a new cell be added to the network once the resources are exhausted in the existing system and this requires further frequency plan revision and user channel reallocation every time a new cell is introduced.

In case of spread spectrum (DS-CDMA) however, universal frequency reuse applies i.e. same frequency can be reused in contiguous cells. Inclusion of new cells, as traffic grows, does not require a revision of frequency plan. Equally significant, as more cells are added, the networks ability to insert and extract energy at a given location is enhanced. Hence, the transmitted power levels of the mobile user and the base station can be reduced significantly by exploiting the power control capabilities.

1.3.2 Capacity

Unlike slotted systems, where different users are assigned disjoint slots of time (TDMA) or frequency (FDMA), the capacity in the CDMA cellular systems can not be defined within the bounds of fixed parameters

In the slotted systems, the capacity is fixed. Whereas in CDMA systems, theoretically, the capacity is flexible. It depends, primarily upon the loading of the cell (interference level), and the quality of service requirements of the individual mobile user. If the interference can be reduced, it directly translates into increased capacity In case of voice signals the use of voice activity reduces the interference and any spatial isolation through use of multi-beamed or multi-sectored antennas, which reduces interference, also provide a proportional increase in capacity. Also more users can be accommodated in a network with slight degradation of the link quality. CDMA exhibits its greatest advantage over TDMA and FDMA in terrestrial digital cellular systems, for here isolation among cells is provided by path loss, which in terrestrial UHF propagation typically increases with the fourth power of the distance Consequently, while

[1] A slotted system is one where all the users are alloted non-overlapping slots (frequency slots for FDMA system and time slots for TDMA systems), for transreceiving their signals

conventional techniques must provide for different frequency allocation for contiguous cells CDMA reuses the same spectrum for all the cells thereby increasing the capacity by a large percentage.

For any multiuser communication systems, the measure of its usefulness is not only the maximum number of users which can be serviced at one time but rather the peak load that can be supported with a given quality (chiefly defined as the link quality exceeding some carrier to interference ratio threshold), availability (measured by blocking probability) and reliability (measured as link margini and dropping probability) The Erlang capacity for a CDMA cellular system is defined as the average number of users that a system supports with a specified value of blocking probability, which is generally taken to be equal to 2 percent or less

As defined earlier the blocking in CDMA system normally results when the interference level, due primarily to the presence of other active users, reaches a predefined level above the background noise level (mainly of thermal origin). While this interference to noise ratio could in principle be made arbitrarily large , when the ratio exceeds a given level (normally taken to be 10 dB), the interference increase per additional user grows very rapidly [1], yielding diminishing returns and potentially leading to instability As the criterion for blocking is not fixed but depends upon the state of the system it is termed as a *soft blocking system* unlike the slotted systems where it is known as a *hard blocking* system.

1.3.3 Admission Control

In slotted systems, if all the available slots within a cell are occupied, the new caller is given a busy signal. With the CDMA system, however, there is a much soft relationship between the number of users and the grade of service. For example, the system operator could decide to allow small degradation in the error rate and thus increase the capacity during the peak hours.

This capacity is essentially important for avoiding dropped calls at hand-off because of a lack of channels. In the analog systems and in digital TDMA, if a channel is not available, the call must be reassigned to a second candidate base station or it will be dropped at the hand-off. With CDMA , however, the call may be accommodated if it is acceptable to slightly deteriorate the users' signal quality.

1.3.4 Reliable Hand-off

In a cellular system when a mobile moves out from one base station's coverage area to another cell's jurisdiction the control needs to be handed over to the new cell's base

station. This process is known as *hand-off*.

In conventional systems, as the adjacent cells operate at different frequency, the mobile can not be simultaneously in contact with more than one cell and so switching-over, which requires new frequency assignment as result of handoff, is termed as *Hard Hand-off* Dropping of calls as a result of hard hand-off has a non zero probability as the new cell may fail to support this new entrant.

The CDMA system supports, what is known as, *Soft hand-off*. In soft hand-off a mobile may be connected simultaneously to more than one base station and the hand-off, which in CDMA case does not require any frequency change (thanks to universal frequency reuse), can be materialized simply by handing over the controlling charge to another base station which is already transreceiving this mobile's signal So dropping can not be a byproduct of this kind of hand-off Moreover,the soft dropping results in more than double the capacity of a heavily loaded system and may result in more than double the coverage area of each cell in a lightly loaded cellular network [1].

1.3.5 Susceptibility to Channel Impairment

Apart from the propagation path loss the signal propagation in a mobile cellular radio network is characterized by the multipath phenomenon. For any cellular system the multipath propagation results in degraded performance, mainly because of fading [2] and to a relatively lesser amount by the ISI (Inter Synbol Interference). In slotted systems (e.g , IS-136) diversity techniques (space, time, frequency) are employed for tackling the fading , and, equalization before detection is used to remove the ISI (e.g., GSM) However, in DS-CDMA system the multipaths can be used to improve the performance, using RAKE reception [3] or at test it can suppress it by a factor equal to the processing gain [4] Time diversity is put to use to exploit the ISI.

1.3.6 Cell Structure

Role of suitable cell structure is quite tangible in conventional cellular systems. A good combination of micro and macro cells with or without hierarchical structures can improve the coverage as well as the frequency reuse capability of the system However,

[2] see Section 2.2

[3] For RAKE reception the paths should be resolvable, i.e. at the receiver the arrival times of any two paths should at least differ by a PN code chip duration so that the paths could be decorrelated with each other.

[4] When the RAKE receiver fails to lock a path to the correct phase it reacts to it as if the signal in that path was spreaded by a different code (because of different time offset) and so attenuates it by the cross-correlation factor (which is ideally equal to 1/Processing gain)

its role in DS-CDMA is less prominent since it does not give any advantage of capacity enhancement etc. as available in slotted systems.

1.4 DS-CDMA Cellular System

We have seen that a CDMA system offers significant flexibility and advantages over its counterparts Now we briefly discuss some of the factors which pose challenges to the system designers and influence the performance of a DS-CDMA system

1.4.1 Code Acquisition and Tracking

First and the foremost operation in the DS-CDMA cellular mobile communication is that the mobile should get affiliated to a base station prior to any communication. The mechanism used for this handshake sort of affiliation should be fast and foolproof

Since in the CDMA systems each base station and mobile station is assigned a unique spreading/despreading code [5], it is required that they be acquired properly before any useful communication can take place.

As such accurate synchronization (to the proper offset of the base station) is one of the most important functional requirement of any spread spectrum system. Typically the process of code synchronization between spreading (incoming) PN code and local despreading (receiver) PN code is performed in two steps. Code acquisition, also known as *coarse synchronization*, is the first step. It is the process of successive decisions wherein the ultimate goal is to bring the two codes into coarse time alignment within one chip interval. Next step is tracking, also called *fine synchronization*, wherein the synchronization errors are further reduced or at least maintained within bound

1.4.2 Spreading Codes and Multiple Access Interference

DS CDMA system performance is significantly dependent on the Multiple Access Interference (MAI) [6].

[5]In IS-95, all base stations spread their signal in forward link with a unique code which is derived from a single PN (Pseudo random Noise) sequence, known as short PN sequence, having unique offset for each base station and all the mobiles derive their codes from another sequence, known as long PN sequence, having distinct offset for each individual mobile

[6]In a multiple access system, the desired signal at the receiver is accompanied by the signals from other users that are simultaneously accessing the system. This results in interference which is termed as MAI.

In the process of providing spreading we require that the spreading sequence should have basically three properties :

- It should provide large amount of spreading [7]
- It should have good amount of randomness so that the spreaded signal appears noise-like to the unintended receiver.
- It should have good correlation properties i.e. the sequence used should have very good autocorrelation properties and very low value of cross correlation with other sequences Special codes, such as maximum length codes, Gold codes, Kasami codes etc. have been devised which have a good combination of auto and cross correlation properties.

Ideally, the spreaded signal should appear as Gaussian noise But complexity in the code regeneration at the receiver imposes restrictions on the amount of randomness that can be incorporated in the code.

Good autocorrelation properties facilitate better recovery of the desired signal which is practically buried in noise,whereby providing good jamming margin Whereas small but finite cross correlation results , what is known as, in MAI, when mobile transmit powers reach at the base station and act as interference for the desired signal.

In the DS-CDMA systems MAI is the biggest source of interference which needs to be tackled by proper interference rejection techniques and efficient power control strategies.

1.4.3 Power control

Power control is the basic necessity of a DS-CDMA system To deal with the unpredictable propagation conditions (due primarily to shadowing and fading of the radio channel and user mobility) and compensate for the distance losses, efficient power control needs to be implemented. The power control in forward link primarily ensures sufficient transmit powers to reach the users at the cell edge Unlike the forward link, where the signals, meant for different users, are orthogonally modulated (using Walsh codes) [8] and also reach at any particular mobile receiver, maintaining the orthogonality However, in the reverse link, though the mobiles transmit employing distinct Walsh codes, the signals reaching at the base station, from different mobiles, cover different

[7] To get large jamming margin

[8] Walsh codes have the unique property that any two codes are orthogonal when integrated over the code period

distances and so , no longer remain orthogonal So. the power control, in reverse link, has much difficult task of combating the *near far effect* The power control requires both, a large dynamic range of operation (to tackle the near-far effect) and very fast power updations (to tackle fast varying channel conditions) This system is interference limited. It means that the capacity and the performance of any such system is highly dependent on the amount of interference present in the system As has been already explained that this interference is predominantly due to MAI so by proper controlling of the individual user's signal power the MAI can be reduced significantly.

Earlier power control methods were mainly designed to combat the *near-far effect*. a condition in which the transmissions received from distant mobiles (from base station) experience excessive interference from nearby mobiles in the uplink and the *corner effect*, a condition in which a mobile receiver experiences a decrease in received signal strength and an increase in MAI as it exits from the cell corner in the down link The recent trends in the power control field not only address these problem but also try to improve the system performance as a whole, viz. increase in capacity, better hand-off, decrease in outage probability, decrease in blocking probability and service hole area [9] and efficient handling of network congestion.

To achieve these targets the employed power control strategy should be feasible, have fast convergence rate and a large dynamic range In a mobile cellular system, both the base station and the mobile continuously adapt various system parameters so as to maintain the quality and reliability of the communication link. The interaction of the two is so controlled that a link causes minimum interference to all other links

Transmitted power is one such parameter that needs to be controlled appropriately and most efficiently. When a mobile interacts with a base station it keeps updating its transmitted power level (using the link power budget information and the feedback command from the base station) depending upon its distance from base station, terrain and channel conditions, load in the system etc..

For a particular mobile (say A)-base station link, if the mobile moves closer to the base station or the channel conditions improves (if it comes out of shadow or some obstruction moves away), the receive power at the base station will increase. If the power control mechanism is not prompt enough to control A's transmitted power, then the signals received from all the other mobiles will be affected, which will degrade the performance of the whole network. These affected mobiles will in turn jack up their powers (in response to the feedback from the base station about the degraded link quality), resulting in higher overall interference in the system. This will again

[9]see Section 2.6.4

prompt mobile A to increase power to maintain its link quality This results in a cascading effect of increasing powers (popularly known as *power warfare*) of all the mobiles causing instability and resulting in complete collapse of the system.

1.5 Motivation for the present work

Operation of a DS-CDMA based cellular system is characterized by the basic features like power control, soft hand-off, location of base station, near-far effect etc. , in order of their importance Power control, which involves a multiparametric and adaptive optimization process, forms the backbone of the system The employed scheme to power control decides not only the feasibility but also the capacity and reliability of the system.

Various power control algorithms have been proposed and evaluated over the years however, because of the complexity of the problem, the theoretical development in this area remained adhoc, and so certain issues like identification and elimination of congestion, diversity reception, variable target CIR requirement (both intentional and unintentional) etc. have not yet been explored and exploited to the fullest extent This was the motivation for the present work to take up the power control in the reverse link, which is more critical of the two links, of a DS-CDMA mobile cellular system . In this work we have developed a simulation tool of a DS-CDMA based urban cellular environment and applied power control schemes, *fixed target CIR*, *soft-drop CIR* and *fixed step size*, to evaluate their performance and investigate the mentioned issues.

1.6 Organization of the thesis

Chapter 2 consists of the issues, criteria and performance measures related to power control. A brief description of the work published in the literature has been presented in the last section of Chapter 2. The subject matter of Chapter 3 is the analysis of, the simulated DS-CDMA environment, and the description of the parameters governing the performance of the simulation model. In Chapter 4 evaluated the performance of the employed power control schemes and discussed the results obtained through the simulation model.

Chapter 2

Power Control

2.1 Introduction

In DS-CDMA systems, power control is a vital necessity. The capacity of a DS-CDMA system is interference limited since the channels are neither separated in frequency nor separated in time, and the multiple access interference is present Any user, transmitting power more than the minimum required level, eats into the capacity of the system and in the extreme case a single user exceeding the limit of transmitted power can even inhibit the communication of all other users.

A power control scheme, that provides a feasible user power assignment while keeping the interference minimum , is a tool, which, when supported by proper admission control, efficient hand-off management and proper cell structure design, provides enhanced capacity and reliable service.

In the Sections 2.2 and 2.3, we have discussed the propagation environment In section 2.4 we have outlined various categories of power control methods for both the uplink and the downlink. Section 2.5 deals with the issues that a power control scheme should address. Section 2.6 enlists the performance parameters that a power control scheme must adhere to In section 2.7 and section 2 8, we have discussed various power control schemes, their power control criteria and their relative performance which have been tested and improved upon, mainly in the last decade and finally introduce the concept of *soft dropping* power control strategy which we have used in our simulation. The implementation and performance analysis has been discussed in Chapter 3 and Chapter 4 respectively.

2.2 Propagation Environment

The signal strength not only depends upon the distance from the transmitter but also on the various details of the physical environment around the transmitter and the receiver, such as terrain, building, and other obstacles in the signal path. The power control systems have to compensate for these signal strength fluctuations typical of a wireless channel. Electromagnetic waves transmitted from the transmitter may follow multiple paths on the way from transmitter to the receiver The different paths have different delays and interfere at the antenna of the receiver. If two paths have the same propagation attenuation and their delay differ in an odd number of half-wavelengths, the two waves may cancel each other at the antenna completely If the delay is an even multiple of the half wavelengths, the two waves may constructively add, resulting in a signal of double amplitude In all other cases (non equal gains, delays not a multiple of half-wavelength), the resultant signal at the antenna of the receiver is between the two mentioned limiting cases. This fluctuation of the channel gain is called *fading* Since the scattering and the reflecting surfaces in the service area are randomly distributed, the amplitude of the resulting signal is also a random variable

There two types of channel fading:

- slow due to shadowing or shadow fading
- fast due to multipath fading and the mobility of the mobile

As the user moves away from the base stations, the receiver system becomes weaker because of the growing propagation attenuation with the distance. As a mobile moves in an uneven terrain, it often travels into a propagation shadow of a building or a hill or other obstacles much larger than the wavelength of the wireless channel. This phenomenon is called *shadowing*

Shadowing in a land-mobile channel is usually characterized by a stochastic process having lognormally distributed amplitude and the amplitude of the fading is usually characterized by a Rayleigh, Rice or Nakagami distribution.

In a recently published paper [23] a composite multipath/shadowed fading environment consisting of multipath fading superimposed on lognormal shadowing has been proposed. In this environment the receiver does not average out the envelop fading due to multipath, but rather reacts to the instantaneous composite multipath/shadowed signal. This is typically the scenario in congested down-town areas with slow moving pedestrians and vehicles. For this purpose composite *gamma/lognormal* pdf has been proposed This pdf arises in *Nakagami-m* shadowed environment and is obtained by

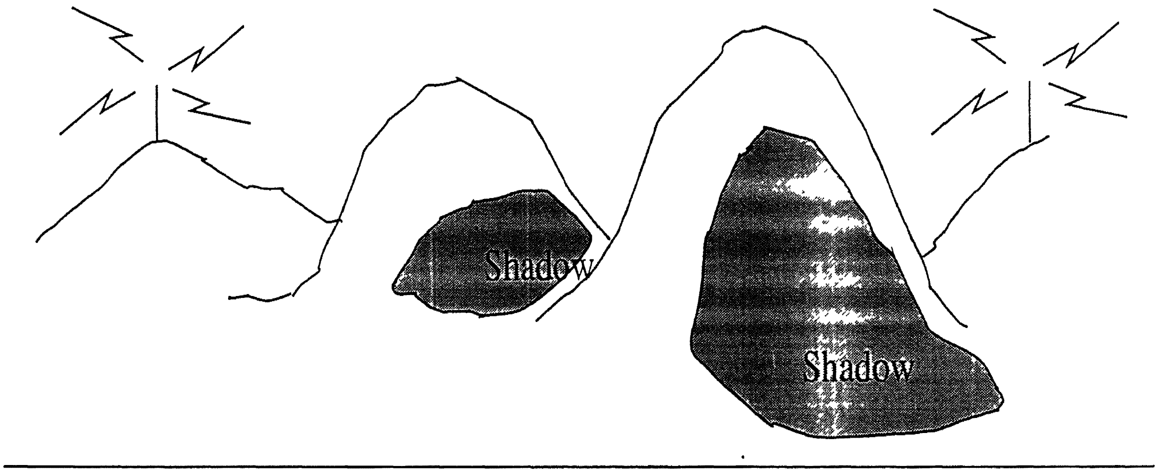

Figure 2.1: Shadow zone [27]

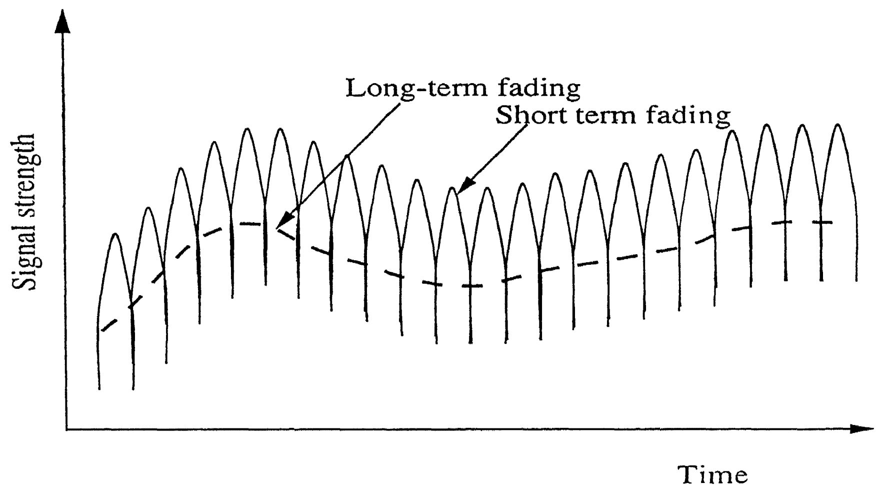

Figure 2.2: Short and long-term fading [27]

averaging the *gamma* distributed signal power over the conditional density of the *log-normally* distributed mean signal power. For the special case when the multipath is Rayleigh distributed, this distribution reduces to a composite *exponential/lognormal* pdf as proposed by Hansen and Meno [24]. Lutz *et al.* [25] have proposed a combined (time shared) *shadowed/unshadowed* model for land-mobile satellite channel characterization. They have found that overall fading process is a complex combination of unshadowed multipath fading and a composite *multipath/shadowed* fading. When no shadowing is present, the fading follows a Rice pdf. On the other hand when the shadowing is present, it is assumed that no direct line of sight path is exists and the received signal power is assumed to follow an exponential-lognormal pdf [24].

Several empirical/semi-empirical propagation models [27], viz. Hata Model, C-CIR Model, Walfisch-Ikegami Model(WIM), Longley-Rice Model, TIREM Model etc.

have also been developed which define coverage area , maximum tolerable propagation loss etc., parameterized upon terrain characteristics, mobile and base station antenna heights and percentage of area covered by buildings etc in different wireless communication frequency bands

As far as power control in second generation CDMA system is concerned, very rapid variations, shorter than about 1 msec., are mostly due to Rayleigh fading phenomenon that can not be reasonably mitigated by power control Only the shadowing and the long-term fading (such as may be experienced by stationary users) can be tackled by power control So we will confine our analysis only to propagation attenuation and shadowing.

By definition, if X is a Gaussian random variable, $\mathcal{N}(m, \sigma^2)$, then the random variable Y, defined by $Y = e^X$, will have lognormal distribution. In general, when a Gaussian random variable is the exponent of any constant, such as e, the resulting random variable is said to be lognormal. So if X is $\mathcal{N}(m, \sigma^2)$ then

$$f_y(y) = \frac{1}{\sigma y \sqrt{2\pi}} e^{-\frac{(\ln y - m)^2}{2\sigma^2}} \tag{2.1}$$

In other words, a Gaussian distribution in dB units is lognormal in absolute units

combining the propagation attenuation and lognormal shadowing, the *link gain* Γ can be given by

$$10 \log \Gamma = -10 m \log d + S(d) \tag{2.2}$$

or

$$\Gamma = \frac{10^{\frac{\sigma \mathcal{N}(0,1)}{10}}}{d^m} \tag{2.3}$$

where d is the distance between the transmitter and the receiver, m is the path loss exponent whose value varies between 2 to 6, which for a typical urban environment is equal to 4. S(d) is the position dependent lognormal shadowing random variable which in dB units is equivalent to $\mathcal{N}(0, \sigma^2)$ Viterbi *et al.* [1, 2] have found through extensive field results that σ varies from 6 to 12 dBs in environments and $\sigma = 8$ dB is the typical value for urban areas.

2.3 Interference

In DS-CDMA systems, the received signals add up and act as interference to the desired signal. In the forward link, though the transmitted signals are orthogonally modulated, but due to multipath reception the received signals lose orthogonality and so add up and give rise to the interference. In the reverse link the transmitted signals are not

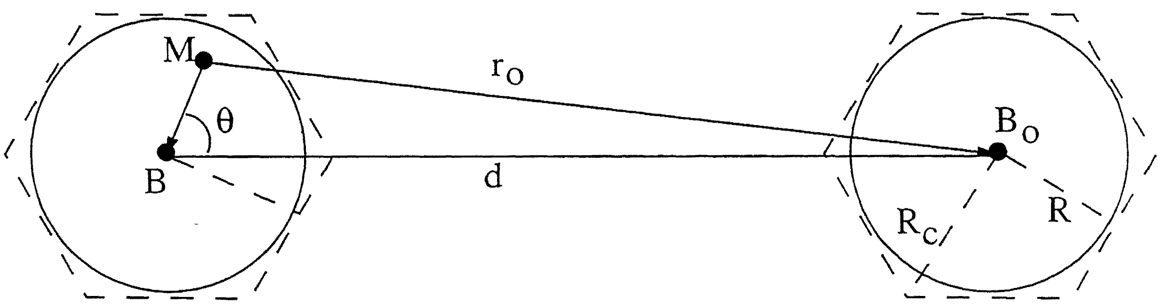

Figure 2.3: Other cell interference

orthogonally modulated and so give rise to interference on reception at the receiver This interference can be modeled as additive band limited white Gaussian noise [27].

In DS-CDMA systems, noise at the base station mainly consists of this interference and for a moderately loaded system the thermal noise is negligible as compared to this interference. The capacity, link reliability and the signal quality of a system are severely affected by the amount of interference present at the base station. That is why the CDMA system is said to be *interference limited*, and not resource limited as the case of any slotted system

The interference can be subdivided into two parts:

- Same cell interference
- Other cell interference

2.3.1 Same Cell Interference

It is the part of the interference which is caused at the base station by the mobiles which are being served by that base station i e. which are within the service area of that base station The mobiles are power controlled dynamically such that the transmitted power reaching at the base station are at the same level so that the capacity can be maximized. So if there are M mobiles in the cell then the same cell interference. I_{SC} faced by a particular mobile will be given by

$$I_{SC} = (M-1)S.\alpha_r \tag{2.4}$$

where S = received power of each mobile at the base station. and
α_r = average *voice activity* factor

2.3.2 Other Cell Interference

In the DS-CDMA systems the frequency reuse factor is nearly unity, so all the mobiles. which are governed by other than a particular base station, constitute the *other cell interference* at that particular base station.

Using the sector coordinate system [20] the total other cell interference, I_{OC} is given by

$$I_{OC} \approx (M\alpha_r S)\xi \tag{2.5}$$

where M = number of users in the cell (assumed equal in all the cells), and
ξ = reuse fraction,

$$\xi \triangleq \frac{\textit{total other cell received power}}{\textit{total same cell received power}}$$

$$\xi = 6\sum_{n=1}^{100}\sum_{i=1}^{n} 2\left[2k^2 \ln\left(\frac{k^2}{k^2-1}\right) - \frac{4k^4-6k^2+1}{2(k^2-1)^2}\right] \tag{2.6}$$

where $k_{n,i} = \frac{d(n,i)}{R}, = 2\sqrt{n^2+i^2-ni}$, $R = \frac{\sqrt{3}R_c}{2}$ and $d = kR$, here d is the center to center distance between the reference base station (central cell) and the interfering base station in the n^{th} ring.

Typical values of $\xi = 0.33$ for radius R,
$= 0.42$ for radius R_c
so $I_{OC} = 0.33M\alpha_r = 0.33$.(total same cell interference) when radius is R, and
$= 0.42$.(total same cell interference) when radius is R_c for $M \gg 1$.
When $n = 3$, $I_{OC} \approx 0.3198M\alpha_r S$ and,
for $n = 100$, $I_{OC} \approx 0.33M\alpha_r S$,

So other cell interference is almost completely represented by the other cell interference arising out of the first three rings (i.e. the central cell and the two tiers around the central cell). It is important here to mention that the level of interference varies with the kind of hand-off employed. It has been analyzed in [2]. and inferred that the use of *soft hand-off* alongwith proper power control, reduces the effective interference considerably and can result in more than double the capacity of a heavily loaded system and for a lightly loaded system can more than double the size of each cell in the network

2.4 Power Control

Power control can be broadly categorized into two categories.

1. Open loop power control

2 Closed loop power control

2.4.1 Open Loop Power Control

The open loop power control estimates the channel and adjusts the transmitted power accordingly, but does not attempt to obtain feedback information on its effectiveness

Each mobile station measures the received signal strength of the pilot signal From this measurement and from information on the link power budget, that is transmitted during initial synchronization, the forward link path loss is estimated. Assuming a similar path loss for the reverse link, the mobile determines its transmitted power.

Obviously the open loop power control is not very accurate, but since it does not have to wait for the feedback information, it is relatively fast. This may be advantageous in the case of sudden channel fluctuations, such as mobile driving out from behind a big building. The inaccuracy in the open loop power control arises out of the assumption that the forward and reverse link signal strengths are closely correlated. Although forward and reverse link may not share the same frequency and, therefore the fading is significantly different, the long-term channel fluctuations due to shadowing and propagation loss are basically the same.

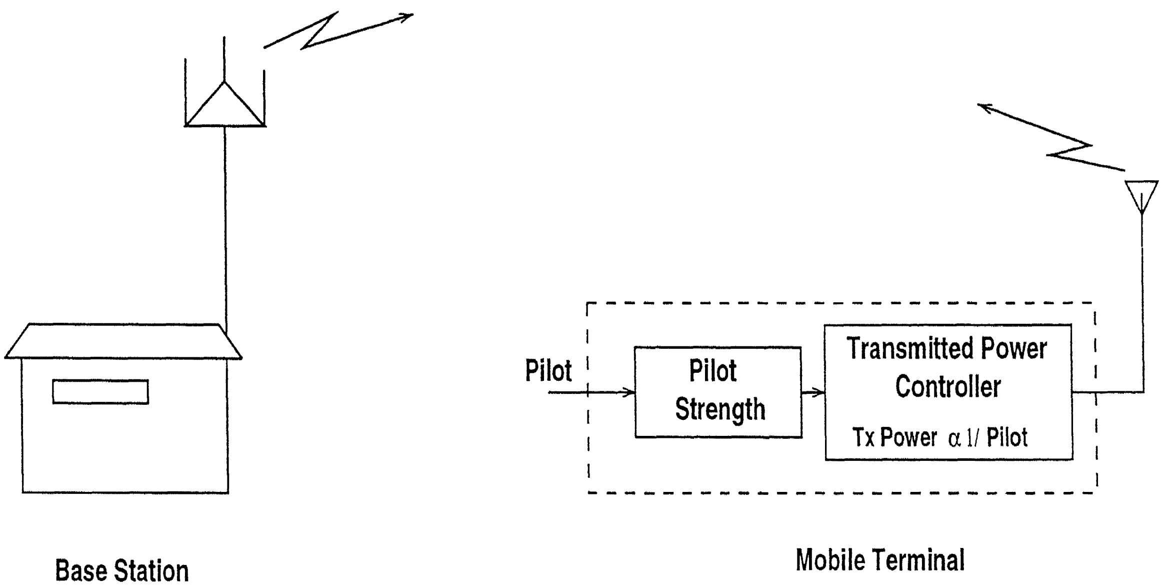

Figure 2.4: Open loop power control

2.4.2 Closed Loop Power Control

The closed loop power control system may base its decision on an actual link performance metric, e.g., received carrier to interference ratio (CIR) received signal power level, received signal to noise ratio, received bit error rate, or received frame error rate.

In the reverse link close loop power control, this metric may be forwarded to the mobile as a base for an autonomous power control decision, or the metric may be evaluated at the base station and only a power control command is transmitted to the concerned mobile

The closed loop power control can further be divided into two subclasses.

1 Centralized power control

2. Distributed power control

In the power control, if decision is made at the base station or at the switching office for all mobiles and is based on the knowledge of all other mobile's performance, it is called a *centralized power control system* [10]. In the distributed power control scheme [9, 15, 14, 19]the decisions are made at the individual mobiles. A centralized power control may be more accurate than the distributed one but it is more complex in design, more costly and technologically more challenging.

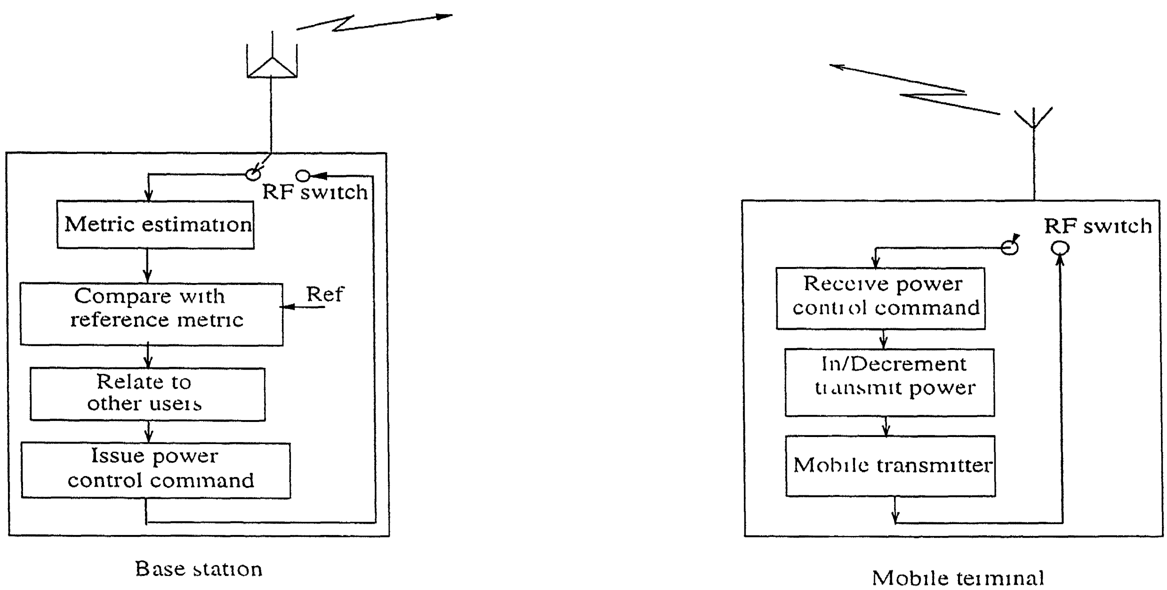

Figure 2.5: Closed loop power control

The closed loop power control consists of two loops, the inner loop and the outer loop The outer loop decides on a target CIR at the end of each frame (20 msec for IS 95 cellular system) and the inner loop provides for the base station to control the power of the mobile with power control command bits, sent every 1.25 msec. i e. 800 power updations per second

Over the years, several power control schemes have been developed [4, 5, 6, 7, 8. 9. 10]. The challenges to these schemes are the fast fading (where the detrimental effects

are generally taken care by employing suitable diversity combining techniques and efficient error correcting codes.), finite delay of the power control system, non-ideal channel estimation, error in power control command transmission, limited dynamic range and the constrained power sources etc.

2.4.3 Forward Link Power Control

The primary purpose for forward link power control is to reduce the power for mobile units that are either stationary, relatively close to the base, impacted little by multipath fading and shadowing effects or experiencing minimal other cell interference. Thus extra power can be given to the users that are either in a more difficult environment or far away from the base station and experiencing high error rates.

2.5 Power Control : Issues Involved

There are several issues that need to be considered while devising a power control scheme

2.5.1 Feasibility

The DS-CDMA system, as defined earlier, is interference limited and so the *quality of service* that the system can support can be translated to *carrier to interference ratio*, CIR, constraints. To satisfy each user's CIR requirement, a set of equations in transmit power levels need to be solved. So a system is said to be feasible, if and only if, a solution to these equations exists.

For a user i, in a conventional DS-CDMA cellular structure

$$\frac{C}{I_i} = \frac{p_i \Gamma[i, C_i]}{\sum_{j \neq i}^{M} p_j \Gamma[j, C_i] + \eta[C_i] W} \tag{2.7}$$

where

M = number of users in the network

p_i = transmitted power of user i

C_i = base station of the cell to which user i is connected

$\Gamma[i, C_i]$ = gain of the path from user i to its associated base station C_i

$\eta[C_i]$ = background noise (Gaussian) power at cell site C_i

W = processing gain

Let the C/I requirement of user i be defined as

$$\frac{C}{I_i} \geq \frac{\alpha_i}{W} \tag{2.8}$$

Here the CIR requirement is normalized by the processing gain W so that α_i depends only on the user and does not vary if we change the processing gain. The feasibility requires that the power control algorithm should ensure fulfillment of individual user's CIR requirement By introducing this condition the power control mechanism basically permits each user to have his own unique bit rate and bit error rate (which is the basic requirement of a multi class mobile communication)

So for minimum power requirement we take equality in the Eqn 2.8 and so

$$p_i\Gamma[i, C_i] = \frac{\alpha_i}{W}\sum_{j=i}^{M} p_j\Gamma[j, C_i] + \eta[C_i]W \tag{2.9}$$

(here it is assumed that M is large so that the interference due to one user is negligible compared to interference due to rest of the users) so we need to find a solution to M transmit power levels corresponding to M users that satisfy the above equation.

In the vector form it can be written as,

$$(\mathbf{I} - \mathbf{A}_{MXM}) = \mathbf{b}_{MX1} \tag{2.10}$$

where, $A[i,j] = \frac{\alpha_i}{W}\left(\frac{\Gamma[j,C_i]}{\Gamma[i,C_i]}\right)$ and $b[i] = \frac{\eta[C_i]\alpha_i}{\Gamma[i,C_i]}$

Since matrix **A** is positive,the Perron-Frobenius theorem says that a unique positive solution exists only when

$\lambda < 1$

where λ is the Perron Frobenius eigen value of the matrix **A**

In Hanly [7], another interpretation of feasibility, for the macrodiversity model is given in terms of the total bandwidth requirement of all the users taken together as against the bandwidth that the system can provide. For each link Eqn 2.8 needs be satisfied where the quantity $\frac{C}{I_i}W$ is defined as the *carrier to interference spectral density ratio* and is denoted by α_i having units of Hz. So for the feasibility of the complete configuration the required condition is:

$$\sum_{i=1}^{M} \alpha_i < KW \tag{2.11}$$

i. e. the sum of individual user's bandwidth requirement should be less than the system bandwidth, KW, where K is the total number of receivers (base stations) that are in macrodiversity with all the users,and W is the processing gain of the system This criterion can be extended to the multi class mobile communication and can be given as

$$\sum_{j=1}^{J} M_j\alpha_j < KW \tag{2.12}$$

where α_j is the CIR requirement of the j^{th} class having M_j number of users

Yates [6] has proved that as the diversity increases, the space of feasible power vectors also increases. The same aspect has been exploited by Hanly [7] in the analysis of power control algorithm for the macrodiversity model

2.5.2 Convergence

The power control algorithm should converge quickly to a solution so that transmit power level changes can be made accordingly and reliable communication is ensured

Yates [6] has, on the basis of standard interference function.I(p), devised a common framework for many power control algorithms and has established their convergence both synchronously and asynchronously. It says,to satisfy C/I requirement of individual users , the power vector **p**, should be such that

$$\mathbf{p} \geq \mathbf{I}(\mathbf{p}) \tag{2.13}$$

where $\mathbf{p} = (p_1, p_2, ..., p_M)$, M denotes the number of mobiles in the system, p_j denotes the transmitted power of user j and

$$\mathbf{I}(\mathbf{p}) = (I_1(p), I_2(p), ..., I_M(p)) \tag{2.14}$$

where $I_j(p)$ represents the effective interference of other users.

$\mathbf{I}(\mathbf{p})$ is standard interference function when it satisfies the following conditions: for $\mathbf{p} \geq 0$

1. positivity i.e. $\mathbf{I}(\mathbf{p}) > 0$
2. monotonicity i.e. if $\mathbf{p} \geq \mathbf{p}' \; then \, \mathbf{I}(\mathbf{p}) \geq \mathbf{I}(\mathbf{p}')$
3. scalability i.e. for all $\alpha > 1, \alpha\mathbf{I}(\mathbf{p}) > \mathbf{I}(\alpha\mathbf{p})$

and the standard power control algorithm

$$\mathbf{p}(t+1) = \mathbf{I}(\mathbf{p}(t)) \tag{2.15}$$

converges both synchronously and asynchronously to a unique fixed point that corresponds to the minimum total power transmission.

Hanly [4] has analyzed the convergence of cell-site allocation for the case of combined power control and cell-site selection and concluded that it is unique and any non-uniqueness (an event of zero probability) shows that the oscillations (of cell-site allocation) back and forth between several cell sites may continue forever For unique solution, this oscillation may be there but, if it is designed so that a user keep connected to a cell-site for a sufficient number of steps before allowing it to handoff to another cell then this oscillation can be greatly reduced.

2.5.3 Dynamic Range

Because of the combined effect of propagation loss and shadowing, the powers received at the base station from different mobiles in a cellular mobile network employing no power control, may differ considerably. The ratio of maximum to minimum powers can be as large as 100 dBs. This causes, what is popularly known as *near-far effect* To effectively power control the system the power control scheme should be able to handle such a large dynamic range of powers

In the wake of constrained power sources, this much large dynamic range is almost impossible to handle. *It is required that size of the cell and the choice of the cell structure be made judiciously so that the operating dynamic range be brought in the practical limits to maintain the reliability and quality of the system.*

In second generation DS-CDMA system (IS-95) the dynamic range of the closed loop is ± 24 dB and that of the composite loop(open plus closed loop) is ± 32 dB

2.5.4 Inaccuracy in Power Control

Reliability and quality of a service that a system can ensure, is directly related with the effectiveness of the power control scheme and that in turn depends upon the rate at which the power control commands are made and the error in the power control command transmission.

The rate at which control commands are made, should be high so that transmit powers be corrected to the desired level in the shortest possible time. But this requires higher overheads and poses difficulty in integrating the commands with the rest of the information signal transmission.

In IS-95, for example, the power control command transmission rate is 800 control bits per second To avoid the delay they are sent uncoded This results in high error ratio, of the order of 5% However, since the power is adjusted continuously up or down, this error rate is tolerable. The error in power control is also modeled as lognormally distributed [1], with 1.1 to 1.5 dB standard deviation. When outer loop power control employs user specific decision threshold at the base station [26], the standard deviation rises to a value of around 2.1 dB which results in about 20% reduction in the capacity

2.6 Performance Criteria

The power control should be performed so that the system satisfies certain performance norms

2.6.1 Blocking Probability

It is the probability that a system denies service to a new entrant in system. In case of DS-CDMA systems, the blocking is termed as *soft blocking* [1], because the condition to block is not fixed but depends upon the instantaneous condition of the system

The blocking, in CDMA systems is not dependent upon the slot availability (as against the time slot in TDMA and frequency band in FDMA case), but upon the transmission quality . It is generally *total interference to background noise level ratio*, which serves as the blocking criterion. This ratio is nominally taken to be equal to 10 dB and the system is designed so that this ratio is not exceeded more than 2 percent of the times Further, corresponding to a particular blocking probability the Erlangs Capacity is defined as the traffic load corresponding to a 1% (or less) probability that the event that "total interference to background noise level exceeds 10 dB, occurs [1].

If we increase this ratio, the capacity can be increased , as higher interference in the system is now being tolerated, but the system's reliability to the user is reduced and the call quality deteriorates. Also, the interference increase per additional user, grows very rapidly, which has a negative impact on the system stability (because now the situation is more conducive for the congestion). However, when traffic is light, much lower *interference to noise ratios* can be imposed which translate into much lower mobile transmitted powers, a particularly valuable feature in prolonging battery life for portable subscriber user

2.6.2 Outage Probability

Outage probability is the probability that some randomly chosen mobile has a CIR below the system protection ratio ψ_o (whereψ_o is the minimum CIR or threshold CIR required by the transmission system). The outage probability (or interference probability) should be minimum. So the outage probability [9] can be given by

$$F[\psi_o] = Pr\{\Psi \leq \psi_o\} \tag{2 16}$$

where,
$\Psi = \{\psi_i\}$ and ψ_i is the CIR of the mobile i.

2.6.3 Dropping Probability

This is the probability that an active user's call is terminated because of poor link quality. This situation may arise because of the following conditions:

- When the mobile comes too close to the base station and is virtually inaccessible to the base station receiver.
- When the mobile's CIR is below the minimum required level and remains so for a certain specified period (permissible outage duration), even though it may be running at its peak power

The later situation may arise when handoff is not materialized because, may be, the candidate base stations are already running at their capacity or the constrained battery power of the mobile transmitter is not sufficient enough to meet the requirement.

In the rare instance, for a power controlled system, when the system is leading to congestion and system is on the verge of *power warfare*, the system's dropping probability shoots up.

The dropping probability should nominally be much lower than the blocking probability that the system can afford as dropping has a much higher annoyance level than a blocking.

For having a low dropping probability P_d, the protection ratio should be high. But very high value of ψ_0 limits the system's capacity and also the battery life. So an optimum value of ψ_0 should be chosen

2.6.4 Service Hole-area

Service hole area should be minimum. It is defined as the area where a mobile's blocking probability is more than 10% [5]. For reliable operation this figure should be as small as possible. Responsibility to keep this area minimum lies on the cell structure designer.

Wu *et al.* [5] suggest an overlaying/underlaying (hierarchical) cell structure to reduce this area and when proper power control algorithm (in which uplink CIR power control for both macrocell and microcell and downlink power control for mirocell is employed) is applied, further improvement is obtained.

2.6.5 Congestion

When a system reaches its capacity limits, congestion becomes imminent and as a consequence the mobile powers and the base station interference level increase.

Congestion could be due to either a local build up of traffic in a cell, or small group of cells or a more uniform build up of traffic in the whole network. In [11], two types of congestion are defined, first,*power warfare congestion*, and the other one is *capacity*

consumption congestion. Former type of congestion is basically local in its spread the later one has the potential to affect the whole network

2.6.6 Soft Hand-off

If a system supports *soft hand-off*, it has got inherent advantages of reliable service (as the dropping probability is considerably reduced), better capacity and larger effective coverage area etc. But the fraction of mobiles in soft hand-off cannot be arbitrarily large

Though, when a mobile is in soft hand-of with two or more base stations, it is always advantageous as far as the reverse link is concerned, because had they not been in soft hand-off, they would have been receiving the same powers but in the form of interference. But in the forward link, it consumes the resource (i. e. base station power) As now the base station will have to transmit power which could have been utilized otherwise for other links.

When two base stations are in soft hand-off, both the base stations generally transmit same powers as when one base station alone would have transmitted to maintain the link As a result, users in soft hand-off contribute twice as much interference as users that are not in soft hand-off.

So the condition that makes the system to put a mobile-base station link in soft hand-off should be selected such that the number of mobiles in soft hand-off is restricted to $1/4^{th}$ to $1/3^{rd}$ of the total mobile population.

2.7 Power Control - Approaches taken

Equipped with other techniques such as diversity (limited or macrodiversity) [4. 7, 11] dynamic cell-site switching [4, 8], and hierarchical structure of cellular system [5, 17], the recently proposed algorithms have attacked the problem of power control with broader objective of attaining power control alongwith maximum gains in terms of capacity, reliability of service (i.e lower outage probability, blocking probability and service-hole-area) and smooth operation (i.e avoidance of congestion and non occurance of power-warfare).

Power control algorithms have been developed broadly on the basis of one of the following criterion :

- constant signal strength at receiver
- CIR balancing or common CIR

- CIR requirement

The algorithms allocate powers to the mobiles and optimize the allocation so as either to minimize total transmitter power [1, 4, 6, 8] or to minimize the outage (interference) probability [9, 15].

When the minimization of total transmitter power is resorted to , the interference is minimized and consequently capacity enhances, battery lives longer and the health hazards (if any) due to electromagnetic radiation are reduced. Whereas when outage probability is minimized the reliability of the transmission against the call dropping is better.

The constant signal strength at receiver was the criterion taken in the earlier versions of power control algorithms This scheme need to have smaller power level dynamic range and so is efficient in controlling adjacent channel interference but has been shown [9] to have limited effect on co-channel interference.

The CIR balancing scheme [9, 12], yields a "fair" distribution of interference in the sense that all users experience the same CIR. CIR balancing has nice property of quick geometric convergence It has been proved in [8] that CIR balancing system reaches the largest achievable CIR level

$$\psi^* = \frac{1}{\lambda^* - 1} \tag{2 17}$$

where

$$\psi^* = max[\psi \mid \exists \mathbf{p} \geq 0 : \Psi_i \geq \psi \; \forall i] \tag{2.18}$$

here ψ^* is the Perron-Frobenius eigen vector of the matrix whose elements are the path link gains between users and base station(s).

But the CIR balancing scheme is not suitable where multiple CIR service is required. It also requires that all the link gains be known before a power control decision can be made. Foschini and Milzanic [19] have proposed a fully distributed and asynchronous power control scheme that solves these problems to a limited extent.

In [5], Wu *et al.* have analyzed the power control using capacity and service-hole-area as performance parameters for both *constant signal at receiver* and *CIR requirement* power control criteria and concluded that *CIR requirement* criterion produces much better results.

2.8 Examples of Power Control Algorithms

Hanly [4] has proposed a power control algorithm which combines cell-site switching and power control in which a set of base stations is defined for each user.

The algorithm is for a cellular CDMA system model which consists of M users labeled 1,2,...,M, are communicating with K cell sites, labeled, 1,2,...,K, and at any given time, user i is transmitting to precisely one of these base stations, c_i Thus the vector $c \in \{1, 2, .., K\}^M$, represents the allocation of mobiles to cells and now, the task is to find *optimal* c, denoted as c^*, alongwith finding an *optimal* **p**, denoted by $\mathbf{p}^*$, where, $\mathbf{p} = \{p_1, p_2, .., p_M\}$, for a given configuration of users.A user i is allowed to connect to a set of base stations , $D_i \subseteq \{1, 2, ..., K\}$ Thus the set of all allowable cell site allocation C(D) is given by

$C(D) \equiv \{c \in \{1, 2, \ \ , K\}^M . c_i \in D_i, i = 1, 2, ..., M\}$

For a user i, the carrier to interference ratio, C/I_i, is

$$\frac{C}{I_i} = \frac{p_i \Gamma[i, c_i]}{\sum_{j \neq i} p_j \Gamma[j, c_i] + \eta[c_i] W} \tag{2.19}$$

where p_i = transmitted power of user i

c_i = base station of the cell to which user is connected

$\Gamma[i, c_i]$ = gain of the path from user i to its associated base stationc_i

$\eta[c_i]$ = external Gaussian noise power at cell site c_i

W = processing gain

Users begin with arbitrary powers $\mathbf{p}(0) \in \Re_+^M$. Here, $p_i(0)$ is the transmitter power level of user i at time zero. The users then adapt their power levels inductively as follows.

Given users are transmitting with power levels given by p_n at step n, the power levels at next step, p_{n+1}, is computed by first computing $t_i^{(k)}(n+1)$, $i = 1, 2, ..., M$, and $k \in D_i$

$$t_i^{(k)}(n+1)\Gamma[i, k] = \frac{\alpha_i}{W} I_i^{(k)} \tag{2.20}$$

$$I_i^{(k)} = \sum_{j \neq i} \Gamma[j, k] p_j(n) + \eta[k] W \tag{2.21}$$

and then defining

$$p_i(n+1) \equiv \min_{k \in D_i} t_i^{(k)}(n+1) \tag{2.22}$$

if c_i minimizes $t_i^{(k)}$ over $k \in D_i$, then $c_i(n+1) \equiv c_i(n)$ otherwise $c_i(n+1)$ is set to be one of the cell sites k that provides the minimum in equation(2.22); if there are more than one such sites, randomly one cell site is chosen.

The convergence of transmitter powers and cell site allocation is established through two theorems viz

Theorem 1. If $(M, \Gamma, \alpha) \in \mathcal{F}(\mathcal{D})$ then $p(n) \rightarrow p^* as\, n \uparrow \infty$,for any $p(0) \in \Re_+^M$,and

Theorem 2 For any starting point p(0), there exists an $N \geq 0$ such that for $n \geq$

N, $c(n) \in c^*(D)$.
and its corollary says: If $C^*(D) = \{c^*\}$ then $c(n) \to c^*$, where, $\mathbf{p}^*$ and c^* represent optimum power and allocation respectively.
In the above equations, $\mathcal{F}(D)$, is the set of feasible configurations(see Section 2 5 1 for details on feasibility) and it is defined in the same paper that triple $(M, \Gamma, \alpha) \in \mathcal{F}(D)$, if and only if there exists an allocation $c \in C(D)$ of cell sites and a vector, $\mathbf{p} > 0$ of transmitter powers such that $C/I_i = \alpha_i$

Hanly [7], has proposed an algorithm for the macrodiversity [1] cellular model which says:
Users begin with arbitrary positive transmit power levels, $\mathbf{p}(0) \in \Re_+^M$ The users then adapt there power levels inductively as follows. Given users are transmitting with powers given by $\mathbf{p}(n)$ at step n, and at the next step

$$p_i(n+1) \equiv \frac{\alpha_i}{W}\left(\sum_{k=1}^{K} \frac{\Gamma[i,k]}{Q_k(n) + \eta_k W}\right)^{-1} \tag{2.23}$$

where $i = 1, 2, ..., M$, and

$$Q_k(n) \equiv \sum_{j=1}^{M} \Gamma[j,k]\, p_j(n) \tag{2.24}$$

which represents the total user interference at receiver k when users are transmitting at powers $\mathbf{p}(n)$. Thus, in step $n+1$, user i is attempting to achieve the minimum C/I requirement,α_i, under the assumption that the interference is same as that at step n. The above algorithm can be summarized as

$$\mathbf{p}(n+1) \equiv T(\mathbf{p}(n)) \tag{2.25}$$

where

$$T : \Re_+^M \to \Re_+^M \tag{2.26}$$

and

$$\mathbf{p} \to \left(\frac{\alpha_i}{W}\left(\sum_{k=1}^{K} \frac{\Gamma[i,k]}{Q_k + \eta_k W}\right)^{-1}\right)_{i=1}^{M} \tag{2.27}$$

The convergence of the transmitted power levels and cell site allocation to the optimum point is established through the following two theorems :
Theorem 3 :
a) If $\sum_{i=1}^{M} \alpha_i \geq KW$ then there is no solution to the equation

$$\sum_{k=1}^{K} c[i,k] = \alpha_i, \;\; i = 1, 2, .., M \tag{2.28}$$

[1]In macrodiversity the base station has antennae that are spread over a wide geographical area, and each antenna (known as base station receiver) listens to a user and the user's signal are then optimally combined.

b) If $\sum_{i=1}^{M} \alpha_i < KW$ then there exists a unique solution to the above equation.

Theorem 4 · If $\sum_{i=1}^{M} \alpha_i < KW$ then from theorem 1, T has a unique fixed point $\mathbf{p}^*$. Then for any $\mathbf{p}(0) \in \Re_+^M$, $T^n(\mathbf{p}(0)) \to \mathbf{p}^*$, as $n \uparrow \infty$,
and if $\sum_{i=1}^{M} \alpha_i \geq KW$ then $T^n(\mathbf{p}(0)) \to \infty$, as $n \uparrow \infty$, this corresponds to the condition of *power-warfare.*

In Zander [9, 15], the global power control algorithm, Υ_Γ. is defined as

$$\mathbf{P} = \Upsilon_\Gamma(\mathbf{Z}) \tag{2 29}$$

where $\mathbf{P} = \{P_i\}$, is the transmitted power levels and $\mathbf{Z}$ is the path gain matrix whose elements, $Z_{i,j} = \frac{\Gamma_{i,j}}{\Gamma_{i,i}}$, are the normalized path link gains from user i to base station j. When $\mathbf{Z}$ contains information about all the links then it represents the global power control algorithm, otherwise, a local power control algorithm.

The objective is to find a optimum global power algorithm that will, by removing as few cells as possible, find the largest sub matrix $\mathbf{Z}^*$ for which ψ_0 is achievable. Here, $\mathbf{Z}^*$, is the matrix whose all rows and columns k corresponding to zero components (which in turn corresponds to the dropped cell k) in the optimum power vector have been removed. Depending upon the dropping mechanism two power control algorithms are defined.

1) Stepwise Removal Algorithm (SRA), and
2) Limited Information Stepwise Removal algorithm (LI-SRA)

The SRA steps are:

1) Determine ψ^* corresponding $\mathbf{Z}$. If $\psi^* \geq \psi_0$ use the eigenvector $\mathbf{P}^*$, else set $Q' = Q$.
2) Remove the cell k for which the maximum of the row and column sums
$r_k = \sum_{j=1}^{Q} Z_{kj}, \quad r_k^T = \sum_{j=1}^{Q} Z_{jk}$
is maximized and form the $(Q'-1)X(Q'-1)$ matrix Z'.Determine ψ^* corresponding to Z'.If $\psi^* \geq \psi_0$, use the eigen vector $\mathbf{P}^*$, else set $Q' = Q' - 1$ and repeat step 2).
In the above algorithm ψ^* is the maximum achievable carrier to interference level as defined in Eqn.2.17, power vector $\mathbf{P}^*$ is the eigen vector corresponding to λ^* (which is the Perron-Frobenius eigen value of matrix $\mathbf{Z}$) and Q is the set of co-channel cells. $\mathbf{P}^*$ actually achieves the same carrier to interference ratio ψ^* in all mobiles, thus making the system balanced.

Gupta *et al.* [28], have used a variable target SIR (Signal to Interference ratio), termed as *soft dropping* SIR, power control scheme. in this scheme target SIR of each mobile is dynamically varied in accordance with its instantaneous transmit power level. As the transmit power level increase in response to the increased interference level or its reduced uplink gain, its target SIR is reduced appropriately. Motivation for doing so is that the chances of getting into a infeasible power configuration situation

are reduced. This helps in keeping the interference in the network within the limits and higher capacity alongwith better system performance is obtained. The convergence of this power control scheme has been established on the basis of Yate's work [6] where the iterative power control method assigns the new power level which is a function of the standard interference function parameterized over the previous power level. The performance improvement with this power control scheme has been further discussed in detail in Chapter 4.

Chapter 3

Simulation Model and Performance Measures

3.1 Introduction

We have seen that a DS-CDMA mobile cellular system can not survive without proper power control In this work we have simulated a mobile cellular environment which incorporates all the mobile environment features that are relevant to the power control problem. Several power control schemes have been applied to this environment to assess their performance in terms of capacity, reliability and quality. As the capacity and other system performance constraints are more stringent in the reverse link, we have considered only the power control schemes that are applied in the reverse link

The parameters that are used as performance criteria, such as criteria for blocking, dropping, hand-off, outage duration, and link margin are not readily available in the literature or otherwise. Moreover these parameters are not fixed as such, they may vary for example with the level of traffic in the network Also these parameters are linked with each other in a very complicated manner. The degree of their interplay also varies. So we have resorted to careful parametric calibration to find the criteria values for performance evaluation of the power control schemes

This chapter is devoted to simulation model that has been developed in this work. In Section 3 2, a DS-CDMA environment having two dimensional macro-cellular structure has been defined. The propagation model used in the simulation, as explained in Section 3.6, incorporates both the propagation path loss and the shadow fading In Section 3.12 we have described the *soft-drop target* power control scheme which is link quality based, asynchronous and distributed power control scheme and aims at providing target CIR to all the mobile-base station links where the target CIR is itself

adaptive. The dropping probability, blocking probability, average transmitted power and average received CIR have been used to analyze the performance of the employed power control schemes

3.2 Cell Layout

In the simulation, individual cells of hexagonal shapes have been considered Number of cells in the network can be 1, 7 or 19, depending upon the required single ring, double ring or triple ring structure. As far as the other-cell-interference is concerned, considering a cell structure, having more than three tiers , does not result in any improvement in the accuracy of the performance analysis of the system [1, 2, 26, 27] [1] So we have limited the network size to three rings only. The base stations are assumed to be situated at the center of the cells *The effective size of the cells is essentially flexible, depending mainly upon the load in the network and the degree of soft-handoff incorporated in the system.*

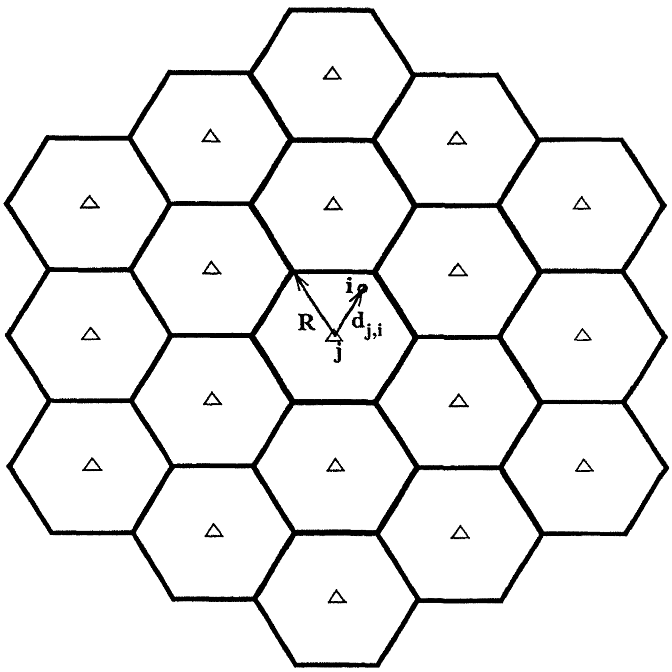

Figure 3.1: Cell layout

[1] see Section 2.3 2

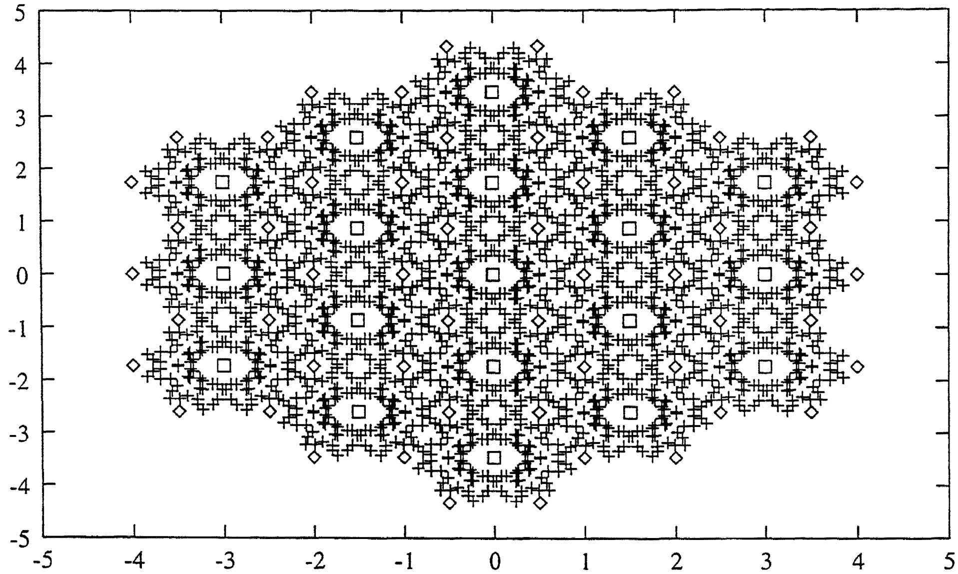

Figure 3.2 Uniformly distributed mobile location pattern

3.3 Mobility Model

A truncated Gaussian distribution has been used to assign speeds to the individual mobiles. The mean and the standard deviation are taken to be 65 Km/hr. and 15 Km/hr. respectively. The minimum and maximum speeds are taken to be 30Km/hr and 100 Km/hr. respectively.

It is assumed that the mobile maintains the same speed throughout the call duration As far are direction of mobile movements is concerned, the mobiles are restricted to move only radially towards or away from the base station. where the base stations is assumed to be situated at the center of their respective cells.

3.4 Mobile Distribution

The mobiles are uniformly distributed throughout the network (as defined by Gilhousen *et al.* [13]). However, the simulation model provides the i flexibility to consider different mobile density level in the network. Fig.3.2 shows a possible mobile density disribution in the networt.

3.5 Call Traffic Parameters

Call arrivals are taken to be Poisson distributed with mean arrival rate λ calls per second. The call durations are taken to be exponentially distributed with mean call

duration $1/\mu$ seconds. The traffic load is therefore given by

$$Traffic\ load \triangleq \frac{\lambda}{\mu} \tag{3.1}$$

3.6 Propagation Model

As explained in Chapter 2, as far as the power control is concerned, the propagation loss consists of two components:

- Attenuation proportional to m^{th} power of distance between the mobile and the base station.
- Slow fading or shadowing, which has a lognormal distribution.

The link gain Γ_{kj} from the mobile at a distance d_{kj} to base k in units of dB is

$$10\log\Gamma_{kj} = -10m\log d_{kj} + S_j(d_{kj}) \tag{3.2}$$

here value of m is taken to be equal to 4 and $S_j(d_{kj})$ is the position dependent shadow fading factor, which is modeled as a zero mean Gaussian random variable with standard deviation $\sigma = 8$ dB.

We have taken a joint Gaussian probability density for decibel losses to two or more base stations. So we may express the random component of the decibel loss as the sum of two components: one is the near field of the user that is common to all base stations, and one that pertains solely to receiving base station and is independent from one base station to another. Thus we may express

$$S_j(d_{kj}) = a\xi + b\xi_j \tag{3.3}$$

where

$$a^2 + b^2 = 1, a \leq 1 \tag{3.4}$$

with

$$E\left[S_j(d_{kj})\right] = E\left[\xi\right] = E\left[\xi_j\right] = 0\forall j \tag{3.5}$$

$$Var\left[S_j(d_{kj})\right] = Var\left[\xi\right] = Var\left[\xi_j\right] = \sigma^2\forall j \tag{3.6}$$

$$E\left[\xi\xi_j\right] = 0\forall j \tag{3.7}$$

and

$$E\left[\xi_j\xi_i\right] = 0\forall j \neq i \tag{3.8}$$

To account for the autocorrelation of the shadow fading over distance, we use a first order auto regression model. A shadow fading pattern is thus generated by applying

this auto regression model. The correlation distance, D, is taken to be 50m and shadow fading measurements are obtained at $\delta d = 20m$ intervals. The autocorrelation of the shadow fading process is then modeled as in [28]

$$R_{S_\sigma}(\Delta d) = \sigma^2 e^{-\frac{\Delta d}{D}} \tag{3.9}$$

If signal strength measurements are taken at equally spaced locations, $d_n = n\Delta d$ for N points on the mobiles path, i e. $d_1, d_2, d_3, ..., d_N$, we have

$$S_\sigma(d_i) = e^{-\frac{\Delta d}{D}} S_\sigma(d_{i-1}) + V_i \tag{3.10}$$

here V_i are the independent and identically distributed normal random variables with $E[V_i] = 0$ and

$$E\left[V_i^2\right] = \sigma^2(1 - e^{-\frac{2\Delta d}{D}}) \tag{3.11}$$

and so

$$Var[V_i] = \sigma^2(1 - e^{-\frac{2\Delta d}{D}}) \tag{3.12}$$

.

3.7 Admission Control

When a new user attempts to enter into the system , it is admitted if it achieves a minimum CIR threshold, Ψ_{new} (which is fixed for all new users), with the base station with which it gets maximum link gain (i.e the base station whose pilot strength is maximum at this mobile's receiver).

Before admitting, it is also ascertained that by its inclusion (operating with a power level assigned to it by the initial power assignment scheme), the interference level at its base station does not exceed a particular specified value. In our simulation this value is taken to be 10 dB above the background noise of thermal origin.

3.8 When to Block

When a mobile attempts to access a channel and finds that the average *interference to noise ratio* is greater than the set limit, which in this simulation is equal to 10 dB. it is blocked. This limit has found support in practical systems also.

This limit may be increased to a higher value, say 13 dB, for heavily loaded systems, but with a slightly degraded quality of service. For lightly loaded networks, it can be reduced to a lower value, 6 dB for example, which will have the effect of reduced

transmit power levels of the mobiles [2]. In a rare case, a call may also be blocked if the cell has already alloted all the channels (i.e. all the Walsh codes are in use) and the link gain of the mobile is below the required admission CIR level.

3.9 Handoff Algorithm

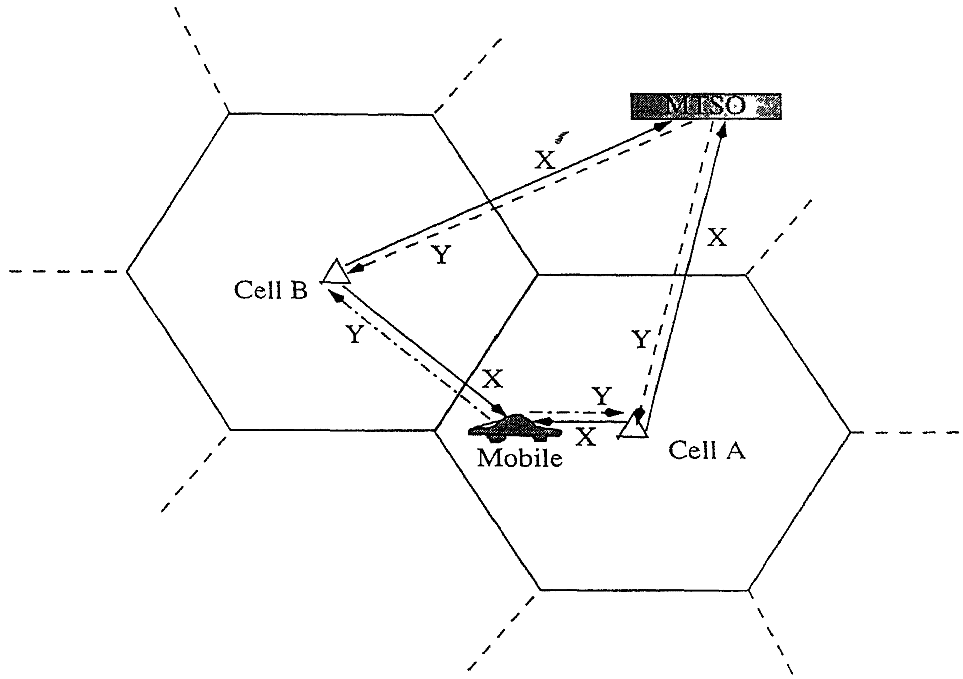

Figure 3.3: **Soft hand-off in the reverse link**

In the simulation, the transmitted signal from a particular mobile is received by all the base stations , though with different received power levels owing to different propagation attenuation, shadowing and fading conditions for different base stations

The individual base stations then report their power levels to the concerned MTSO (Mobile Telephone Switching Office). MTSO in turn arbitrates in favour of the base station, say A, which has reported maximum received power and hands over the control of the traffic for that mobile, along with other control signals, to base station A. A now becomes the parent base station for this mobile and other base stations are put on the *hand-off candidate* list. This criterion corresponds to the minimum mobile transmit power.

[2]Performance of the system with different *interference to noise ratio* is part of the analysis, presented in Chapter 4.

While a particular mobile-base station link is active, if any base station, from the candidate list, receives power exceeding that received by the parent base, A, by a specified amount [3], say 6 dB, and continues to receive so for a specified period [4], the MTSO orders for hand-off and transfers the control to that base station, say B, along with the command asking the base station B to allocate a traffic channel to this mobile The base station B becomes the parent base station until next hand-off (if necessary) and A is put on the candidate list However, if the base station does not have a free traffic channel with it (which is quite a rare case), the base A continues as parent until another base station provides feasible condition for hand-off

3.10 Diversity

Both base station diversity and the multipath diversity have been incorporated in the simulation model.

As all the base stations are receiving all the mobiles' signals and reporting to the MTSO, which in turn decides in favour of the strongest mobile-base station link This in essence simulates the effect of selection diversity. As far as multipath diversity is concerned, its effect has been simulated in the form of RAKE reception at the base station, where multipath signals, belonging to the same-base station link, are combined, assuming ideal RAKE reception

3.11 When to Drop

When an active mobile's *carrier to interference ratio* goes below the *drop threshold*, Ψ_{drop}, and remains below this level for a period of 2.5 sec., its call connection is terminated. This cushion of 2.5 sec., which has been obtained through multiparametric dynamic performance optimization process of the used simulation model, incorporates the *outage duration* [5] concept of the DS-CDMA system.

If the outage duration is reduced, it will increase the dropping probability. However, if its value is increased to a high value, it will cause a larger number of mobiles, running at their peak power level (which may be discarded, if continue to work under the same environment) and so they will force the other users to operate at higher powers As a

[3]this prevents the unnecessary handoffs where only minor improvements can be made

[4]this delayed handoff prevents the *ping-pong effect* when the mobile switches frequently between two base station jurisdictions, wasting precious network resources in the form of overheads

[5]the concept of *outage duration* is defined in the Section 2.6 2 and its impact on the system performance has been analyzed in Chapter 4.

result, the average interference level in the network will go up resulting in excessively high blocking probability and if the *interference to noise ratio* criterion for the blocking is increased, then, in the extreme case, it may even lead to instability.

3.12 Soft Dropping Parameter

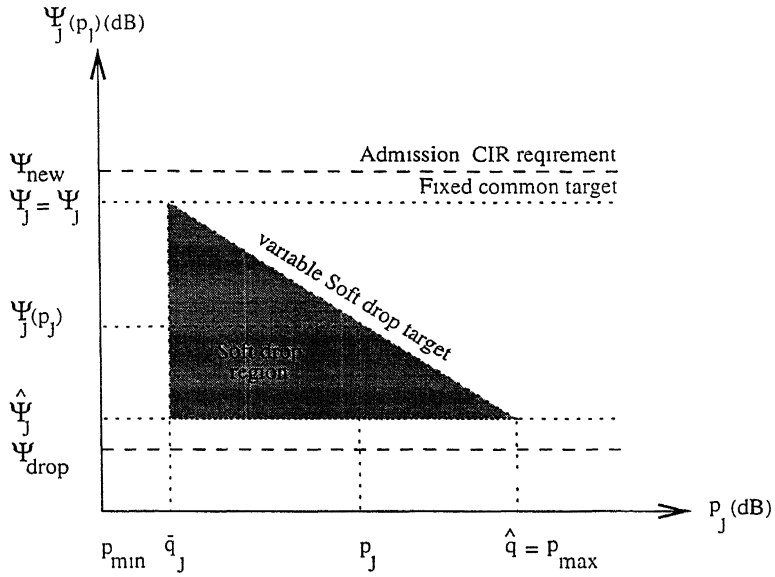

Figure 3.4. Soft dropping power control scheme

In the simulation we have used the *soft dropping* power control scheme and compared its performance with other power control schemes viz *fixed target power control* and *fixed step size power control* scheme. The basic concept is that the target CIR is not a fixed value, but a variable one that ranges from a maximum $\overline{\Psi}$ to minimum $\hat{\Psi}$. As a mobile raises its transmitted power, in response to either increased interference or reduced uplink gain, that mobile will lower its CIR target. That is, as we would normally approach an infeasible power control problem in which transmitted powers rapidly escalate, the variable target CIR algorithm encourages a user to aim for a lower CIR target to increase the likelihood that all users can be supported. Thus when there is high interference at the base station, the power control strategy forces the mobiles operating at high powers to aim for lower target CIRs in order to keep the interference in the system low.

Since the a user's target CIR gradually decreases as its transmitter power rises, the scheme is termed as *soft dropping power control.* This algorithm is fully decentralized, in the sense that the only inputs to the algorithm are the carrier to interference ratio, CIR, received power, and the interference measured at the receiver. Thus it can be

implemented at the base station without requiring any information from other base stations It is assumed in the analysis that the parameters necessary for performing soft dropping power control are accurate and available any time at the base or to the user's terminal

If there are M users in the system, with individual powers p_j, $j = 1, 2, 3, ..., M$ and having link gains $h_{k,j}$, $k = 1, 2, 3, .., K$ (i.e. link gain of user j with the base k), then the CIR of user j at its assigned base station a_j will be given by .

$$\psi_j(\mathbf{p}) \triangleq \frac{p_j h_{a_j,j}}{I_j(\mathbf{p})} \tag{3.13}$$

where $I_j(\mathbf{p})$ defines the interference at the base station a_j and is equal to

$$I_j(\mathbf{p}) = \sum_{i \neq j} h_{a_j} p_i + \eta_0 W \tag{3.14}$$

where η_0 is the noise power spectral density at the base station a_j (taken to be equal for all the base stations).

In the case of fixed target power control algorithm, the required condition for a link would have been

$$\psi_j(\mathbf{p}) \geq \Psi_j \tag{3.15}$$

but for soft dropping power control scheme it is defined as

$$\psi_j(\mathbf{p}) \geq \Psi_j(p_j) \tag{3 16}$$

To achieve this target, the iterative power control scheme employed is given by the relation ·

$$p_j(n+1) = \left(\frac{\Psi_j(p_j)}{\psi_j(p_j)}\right)^{\beta} p_j(n) \tag{3 17}$$

here $\Psi_j(p_j)$ defines the target CIR of the mobile j For the soft dropping case it is defined as

$$\Psi_j(p_j) = \begin{cases} \overline{\Psi}_j & p_j \leq \overline{q}_j \\ \Psi_j^{(v)}(p_j) & \overline{q_j} < p_j < \hat{q}_j \\ \hat{\Psi}_j & p_j \geq \hat{q}_j \end{cases} \tag{3.18}$$

In the equation 3.17, β is a constant, constrained as $0 < \beta \leq 1$. It determines the rate of convergence of the power control scheme. It's impact on the system performance has been discussed in Chapter 4. $\overline{q_j}$ and $\hat{q}_j$ define the lower and upper power limits of the soft dropping zone as shown in Fig. 3.4, and $\overline{\Psi_j}$ and $\hat{\Psi}_j$ are the CIR target limits corresponding to $\overline{q_j}$ and $\hat{q}_j$ respectively.

3.13 Outline of Simulation

First of all the parameters that govern the physical environment, consisting of cell layout, base station lacation, mobile population density distribution and shadowing distribution are set.

As shown in Fig.3 5, the simulation run starts with initialising the system clock T, and in each step it is incremented by 0.00125 seconds (i.e. updating 800 times per second). In each step system checks for a new arrival When a mobile arrives (as per the arrival pattern), it is assigned location, shadowing and velocity parameters. It is then included in the system temporarily, if it survives the blocking condition, Part I, (which includes the condition that the base station to which it belongs has a spare channel and also the interference is within limits), otherwise it is blocked. If it survives, it is then assigned initial power and cheked against the blocking condition, Pat II (which checks for the condition that its inclusion should not render any of the active mobile in the network). If it fails here, it is blocked and if it survives here also then it is made an active user by assigning its remaining parameters, such as its identity, power, affiliated base station, list of hand-off candidate base stations etc.. The base station also updates its list of active and hand-off mobiles. The mobile is now integrated with the active mobile queue structure.

Once it has become an active member of the system, its position, shadow parameter-s, hand-off and various other status parameters are checked in each cycle in accordence with the processes included in the *Updation and performance evaluation block*. Detailed flow graph of the processes included in this block are given in Fig.3.6. In the last part of this block , system statistics pertaining to number of blocked calls, dropped calls, average transmitted and received powers, average received CIR etc. are updated. This complete process continues for the specified simulation time.

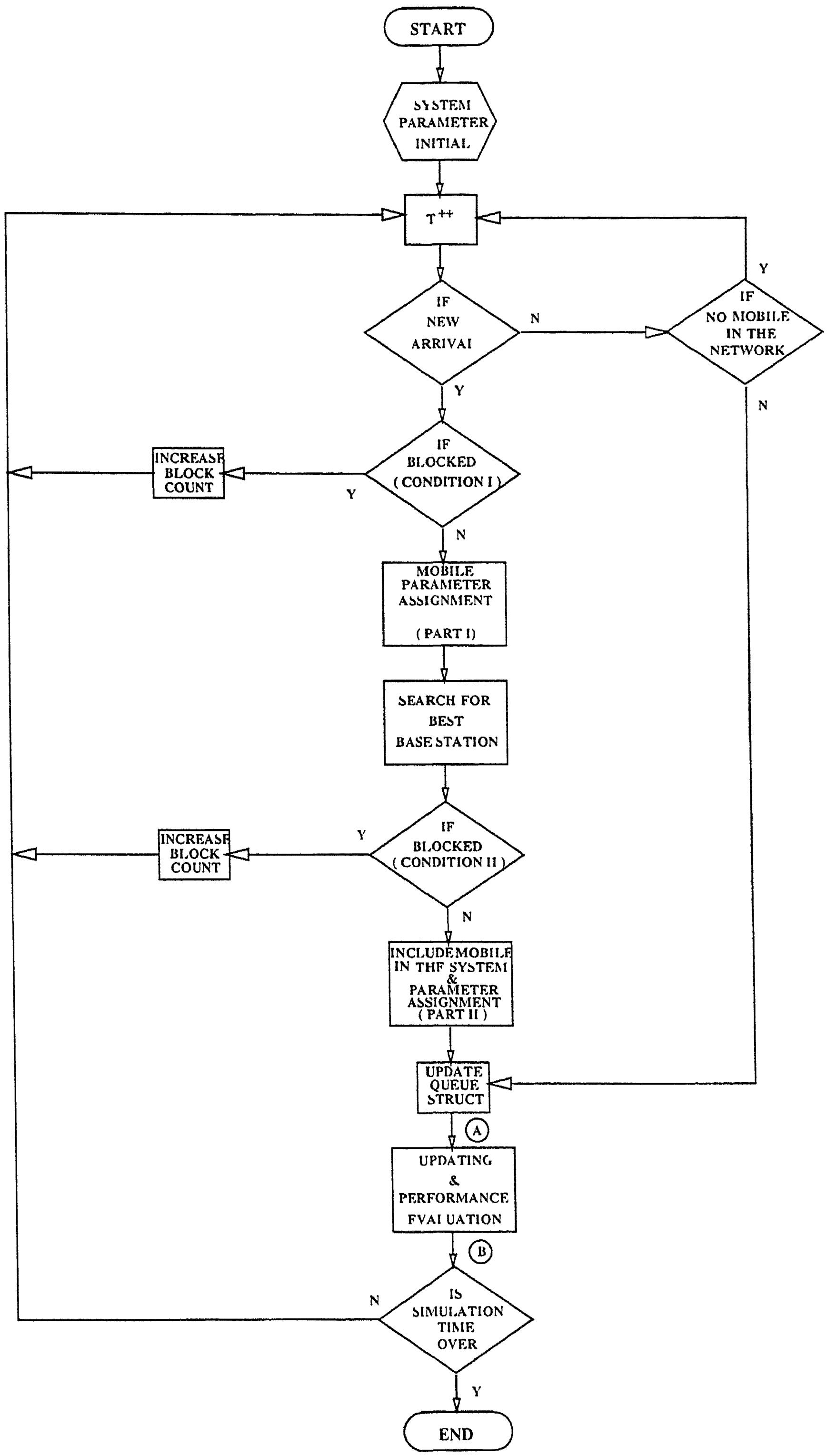

Figure 3.5 Simulation flowchart

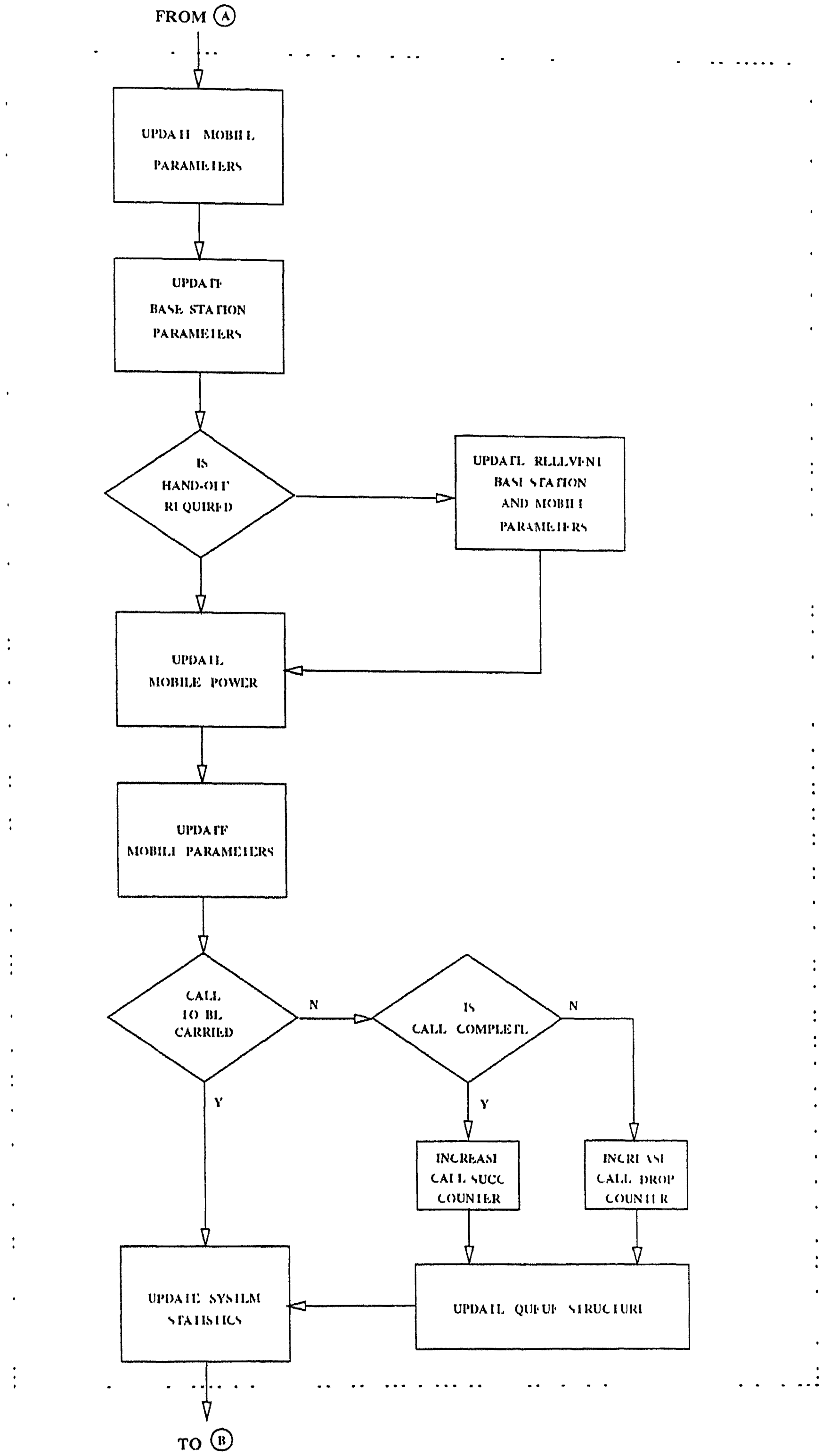

Figure 3.6: Processes within the *Updation and performance evaluation* block of Fig.3 5

Chapter 4

Simulation Results and Discussion

4.1 Introducton

In a DS-CDMA system the parameters such as cell size, limiting and operating transmit power levels, target CIR levels, criteria to admit, block or drop, to go for hand-off or delay it , can only be chosen taking into account the interplay they have amongst themselves. As such the parameter biasing within a stable operating zone is the most crucial exercise, as far as the system performance evaluation is concerned, because changing a single parameter influences all other parameters to different degrees , producing a totally different dynamic performance of the system.

4.2 Power Control Operation

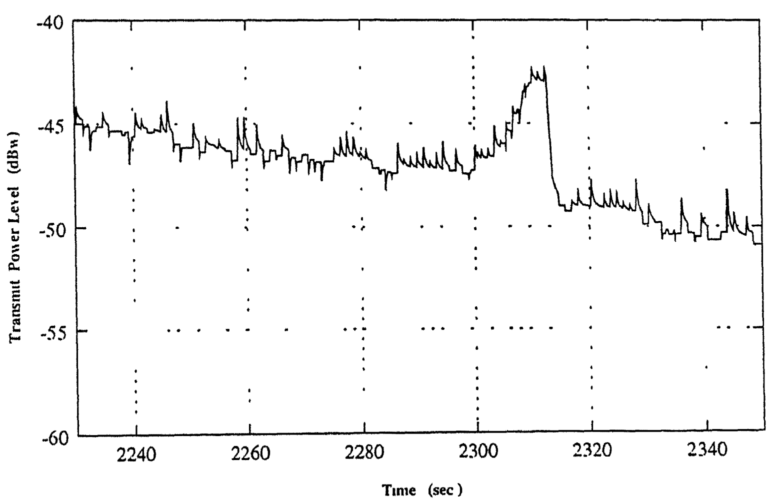

Figure 4.1: Transmitted power level variation of the mobile A (moving towards base station)

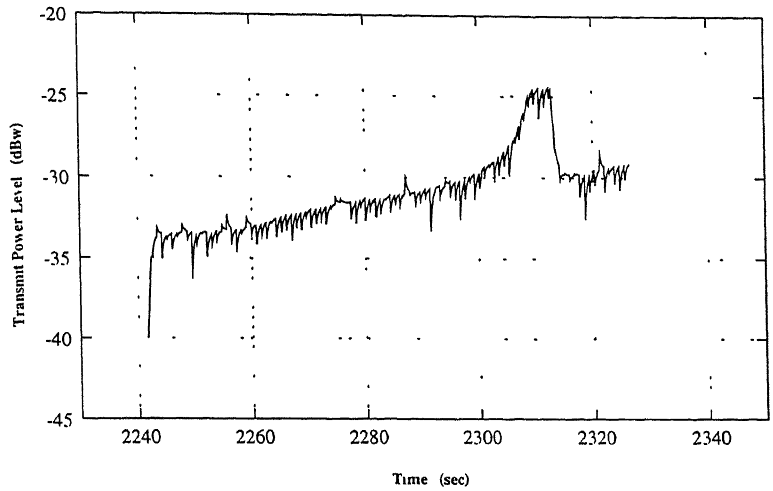

Figure 4.2: Transmitted power level variation of mobile B (moving away from the base station)

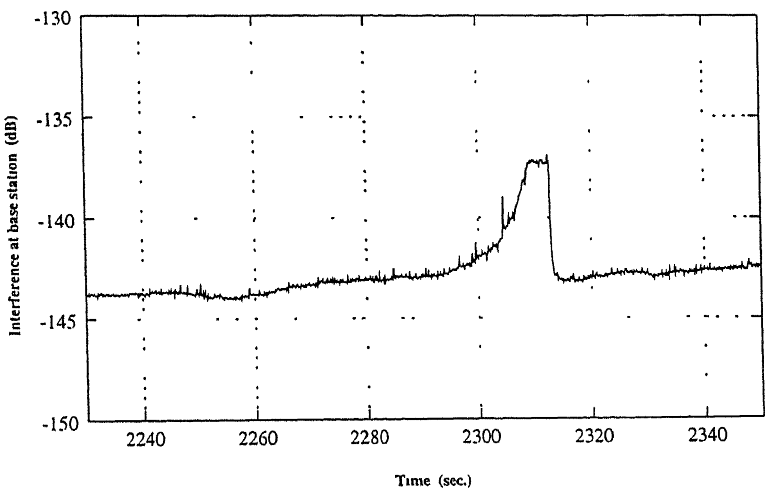

Figure 4.3: Interference Level at the base station

Fig.4.1 and Fig.4.2 depict the updation of transmitted power level , by the employed power control scheme, of two mobiles (both affiliated to the same base station) as a response to the interference level, shown in Fig.4.3 faced by them. These figures show that the power control mechanism controls the powers such that the power variations for both of them though follow the interference variation pattern, but the average power for mobile A is decreased, as it is moving towards the base station, and that of mobile B is increased because it is moving away from the base station.

Fig.4.4 and Fig.4.5 show the impact of the power control on the received power and received CIR of two arbitrarily selected mobiles, mobile A and mobile B. As guided by the employed power control scheme, the power levels are updated (in this particular

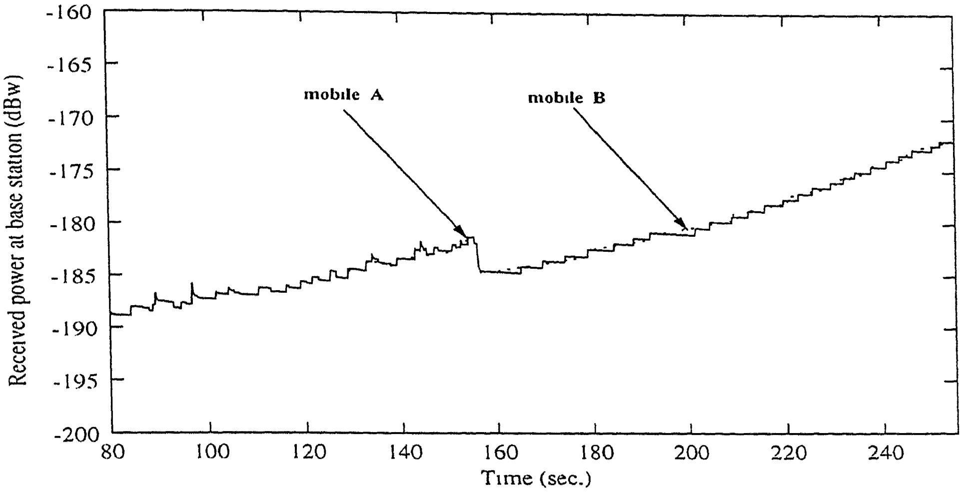

Figure 4.4: Received power of two mobiles affiliated to the same base station

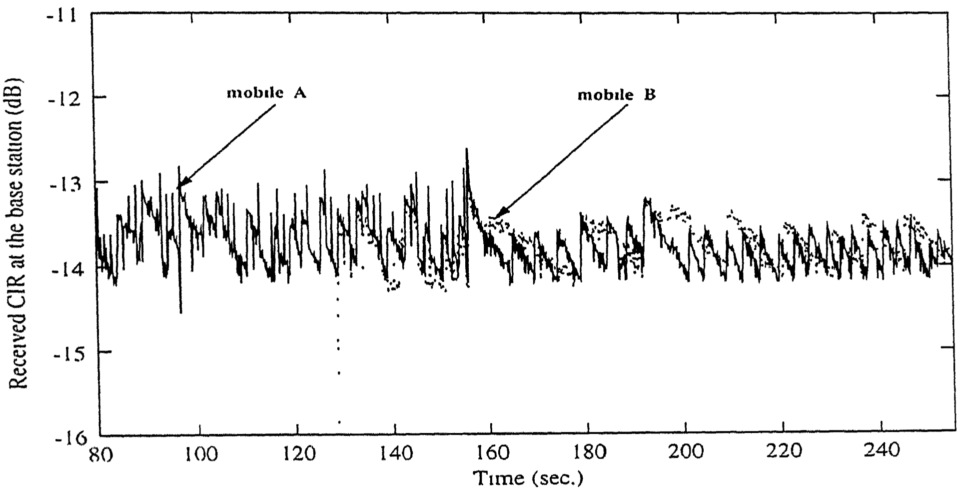

Figure 4.5: Received CIR of two mobiles affiliated to the same base station

case, they are increased), for both the mobiles, in response to the increased interference level so as to ensure sufficient CIR at the reception. The important point here is that, the transmitted power levels of both the mobiles are being controlled in such a manner that they are received at almost equal power level, throughout the updation process This is the very purpose, a power control scheme is used for. as it equips the system to combat effectively the near-far effect.

4.3 Fixed Target vs. Soft-dropped Target

First, we have compared the blocking and dropping performance of the system with a fixed target CIR (Scheme A) and soft-dropped target CIR (Scheme B) power control schemes. The target CIR for Scheme A has been taken as -13.0 dB and the soft-

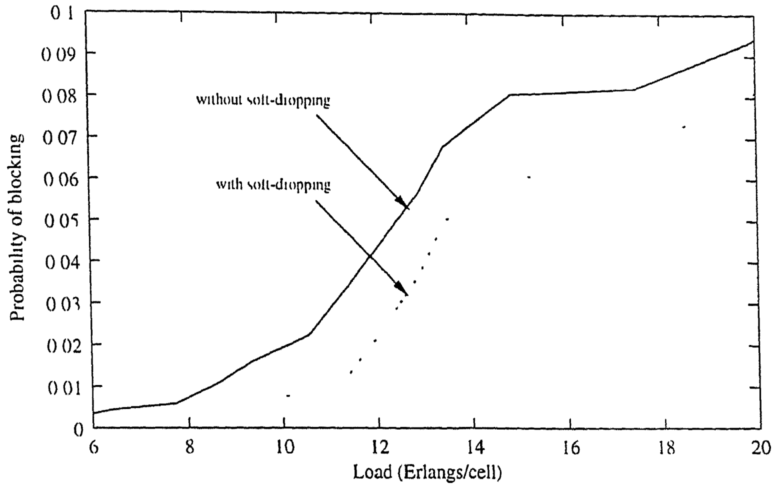

Figure 4.6. Blocking probability. with the soft dropping and without soft-dropping (Fixed target)

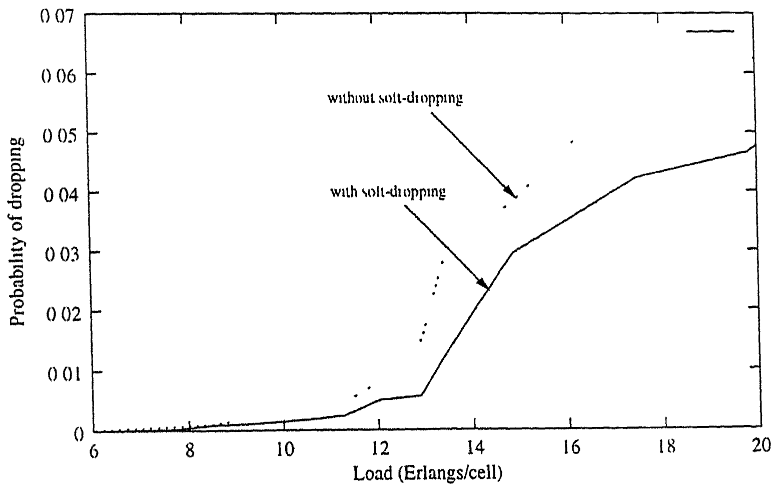

Figure 4.7· Dropping probability. with the soft dropping and without soft-dropping (Fixed target)

drop range for target CIR for Scheme B is taken as -15.0 dB to -13.0 dB and the corresponding soft-drop transmit power range is taken as -3.0 dB to -60.0 dB.

As shown in Fig. 4.6 and Fig. 4.7, for a lightly loaded system, the interference level in the system is low and so the mobiles aim for higher target CIRs as they are operating at lower power levels. But as the load increases, the transmit powers also increase to cope up with the increased level of interference. While the mobiles in Scheme A keep the same target CIRs, the mobiles in Scheme B aim for lower target CIRs (according to the soft-drop pattern) and so the mobiles in Scheme B operate at lower power levels and offer lower interference to the network compared to the network which is employing the fixed target power control scheme. So in a network, using Scheme A, for higher

loads, more mobiles would be operating at their peak power (or at least at the higher end of their power levels) levels resulting in higher call dropping rate and since the interference level is high the blocking probability will also be high. However, the cost paid by the mobile users in Scheme B is, slight degradation in the quality of service

In Fig. 4 8 and Fig. 4.9, we have shown the quality of service degradation in Scheme B as compared to Scheme A as a function of load. This figure outlines the importance of the choice of target CIR range, which should be selected to strike a balance between improvement in dropping and blocking performance and acceptable degradation in the call quality [1].

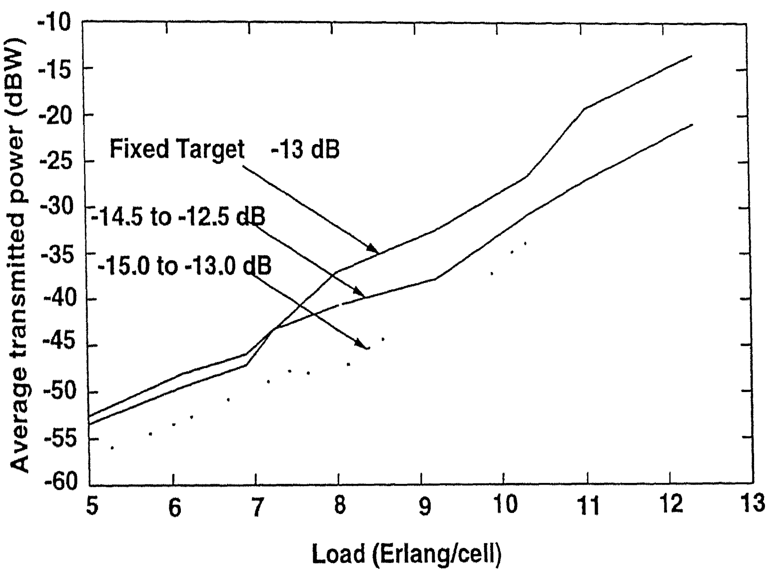

Figure 4.8: Average mobile transmitted power with different target CIR soft drop ranges

4.4 Fixed Step Size vs. Variable Step Size

In Fig.4.10 and Fig.4.11, we have compared the blocking and dropping performance of the network with the fixed and variable step size power control schemes with the same criteria for blocking and dropping as that used for the soft-drop target system (where these criteria values were obtained when different criteria defining parameters were maneuvered, one by one, inorder to improve the overall performance).

As shown in Fig.4.11, the dropping prabability with fixed step size power control scheme is very high (practically, rendering the system useless even at moderate load).

[1] see Section 4.5.1 for a discussion on soft-drop target CIR range selection.

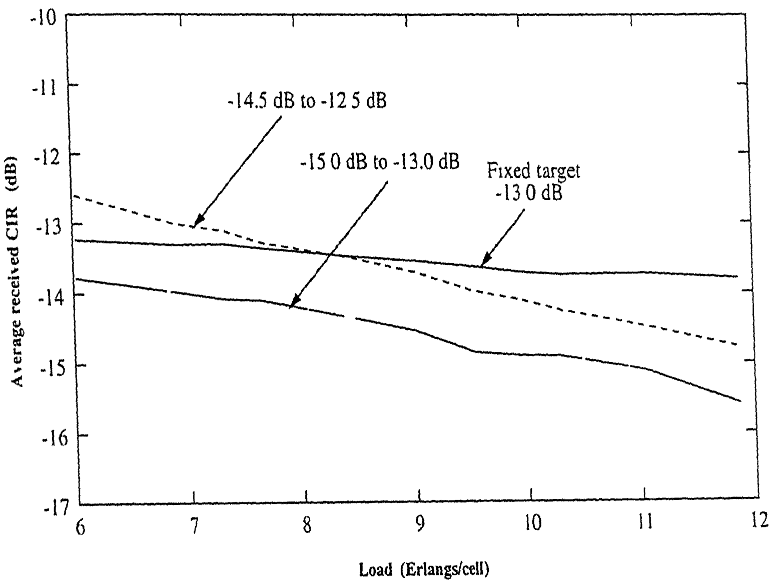

Figure 4.9: Average CIR achieved with different target CIR soft drop ranges

Due to this much high dropping, active mobiles in the system are reduced considerably and so the active load and the interference in the system are reduced resulting in lower probability of blocking compared to the variable step size power updation scheme. Though the blocking appears favourable in fixed step size case, however, when we carefully calibrate the parameters in order to make the system's dropping probability reasonable (atleast comparable to that with the variable step size case ass in Fig.4.11) as far as the dropping probability is concerned (mainly by making the dropping more difficult), we get, in fact, a higher blocking compared to variable size power control scheme. This proves the superiority of the variable step size power control scheme over the fixed step size power control sheme. That is why we have used the variable step size power updation scheme in our simulation model.

4.5 Effects of Parameter Variation

4.5.1 Effect of Soft Range Parameter Variation

In this section we explain the system behaviour and performance, in general, and, average mobile power and received CIR in particular, under different ranges of soft-drop target CIR and soft-drop transmit powers, for the soft-drop power control scheme and then we will compare them with the fixed target power control scheme.

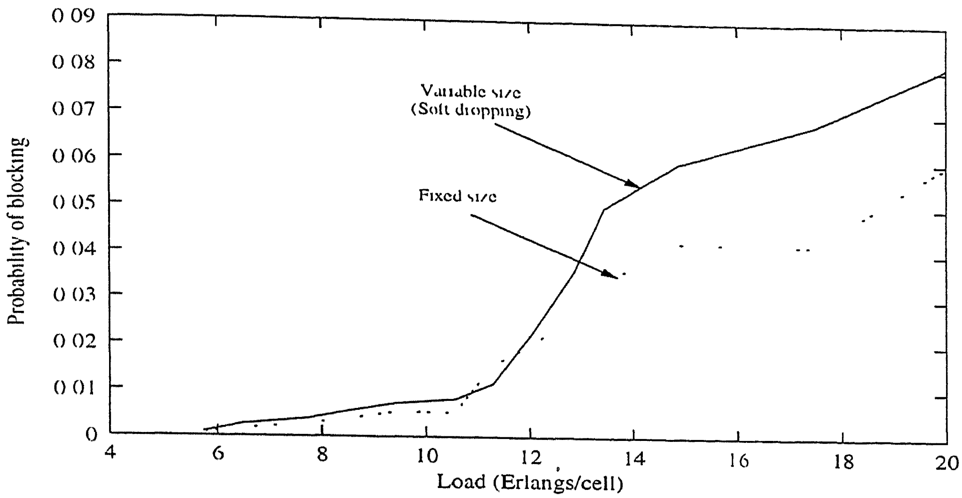

Figure 4.10: Blocking performance with fixed and variable step size power control

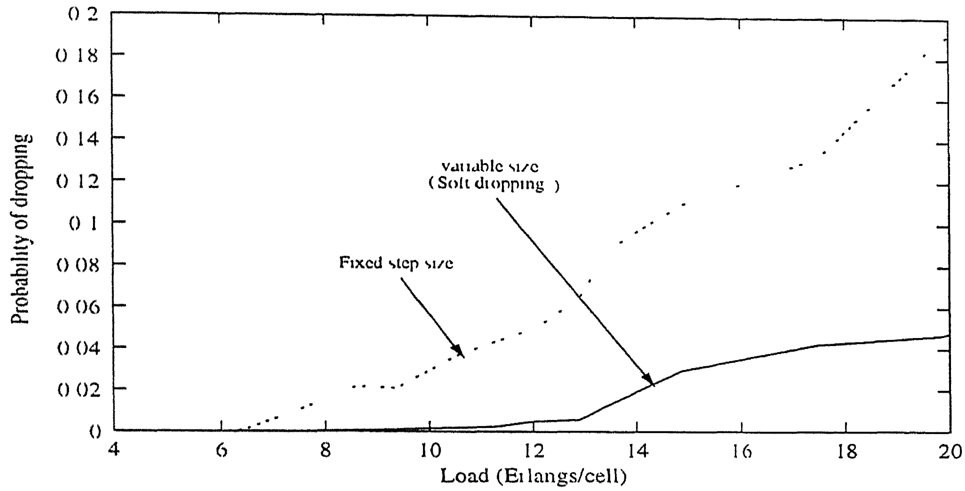

Figure 4.11: Dropping performance with fixed and variable step size power control

4.5.1.1 Soft-drop target CIR range

As the load offered to a network increases, the overall interference in the network goes up, forcing the active mobiles to operate at higher power levels. For a lightly loaded network the increases in average power levels is comparable in all the three ,fixed target CIR (target CIR of -13.0 dB), soft-drop A (with target CIR range -15.0 dB to -13 0 dB) and soft-drop B (-14.5 dB to -12.5 dB) power control schemes, as shown in Fig. 4.8.

As explained in Section 4.3, the system employing the fixed target scheme forces the mobiles to increase their transmit power levels keeping the same target CIR i.e -13 0 dB, whereas in soft-drop A,the mobiles aim for lower target CIR as their transmitted

Number of frequency bands	(BW = 1 25 MHz)	1
Number of Base Stations		19
Receiver Noise Power Density	(dBm/Hz)	-169
Propagation Path Loss Exponant		4
Std deviation of Shadow Fading	(dB)	8
Shadow Fading Correlation Distance	(m)	50
Maxi Mobile Speed	(Km/hr)	100
Mini. Mobile Speed	(Km/hr)	30
Mean Mobile Speed	(Km/hr)	65
Maxi Mobile Transmitter Power	(dBw)	-3 0
Mini Mobile Transmitter Power	(dBw)	-80
Mini CIR Level for Admission	(dB)	-11
Drop CIR level	(dB)	-16
Delay Time for Dropping	(seconds)	2 5
Interference to Noise Density Ratio for Blocking Criterion	(dB)	10
Delay Time for Hand-off	(seconds)	5 0
Level difference for Hand-off	(dB)	6
Number of Paths for Diversity Combining		2
Timer for Statistics Updation	(seconds)	1 0
Time Between Each Power Updation	(seconds)	0 00125

Figure 4.12: Simulation Parameters

power increases [2]. Consequently the average transmit power in soft-drop case is much lower compared to fixed target power control scheme. This improves the blocking and dropping performance as well as the capacity of the soft-drop power controlled system. However, the quality of service is slightly degraded in this process.

Fig. 4.8 also shows the comparison of two soft-drop power control schemes. When the network is lightly loaded the average power requirement is higher in scheme B (even higher than that for fixed target, because the target is -12.5 dB for lightly loaded condition) than scheme A. The two curves diverge as the load increases.

In Fig. 4.9, clearly explains the need to optimize the soft-drop target CIR range selection, to strike a balance between the improvement in system performance parameters of blocking, dropping and system capacity (and also battery life), and the quality

[2] In the soft-drop power control scheme, the target CIR value of -13 0 dB corresponds to the target CIR, the mobiles aim for , when the network is lightly loaded, and -15 0 dB is the target CIR for a heavily loaded network

of service the system can provide.

4.5.1.2 Soft-drop transmit power range

Fig 4.13a shows the average transmit power level variation with load, for the three cases, one corresponds to the fixed target CIR and rest two belong to soft-drop power control scheme with soft-power ranges of -3.0 dB to -40dB and -3 0 dB to -60.0 dB. As explained in the previous subsection, the transmit power level increase in response to the increased interference level in the system caused by increases offered load to the network. But the increase in soft-drop cases is lower than that in the fixed target case, mainly because the mobiles reduce their target CIR as their power levels are increased, which enable the mobiles to operate at relatively lower power levels (satisfying their modified (reduced) CIR targets).

Fig 4.13b shows the average received CIR for the three cases mentioned above

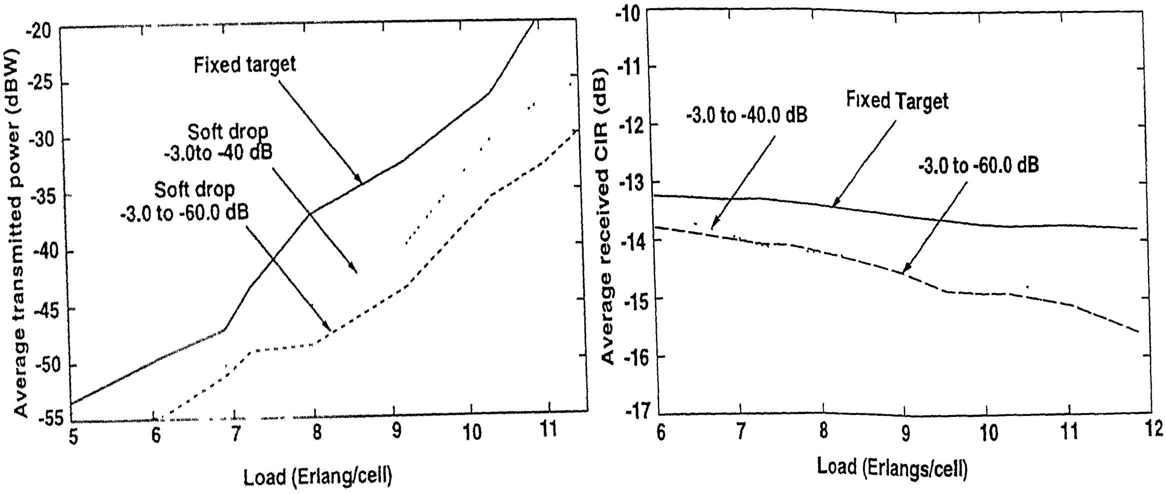

Figure 4.13: a) Average mobile transmitted power with different soft-drop power ranges b) Average received CIR with different soft-drop power ranges

4.5.2 Convergence Parameter

Fig.4.14 and Fig.4.15 show the effect of different β values on the power adaptation in individual steps and Fig.4.16 shows its effect on the convergence rate of the power control scheme. It is clear from Fig.4.14 and Fig.4.15 that as β is increased, on the one hand, the power variation per step increases but on the other hand the convergence rate improves. In Fig.4.17 we have shown that as the β is increased average mobile transmitted power is reduced but at the same time the the call quality (represented here by the received average CIR) is deteriorated. From extensive runs of the simulated

model, we infer that when the β is taken around 0.6 to 0.7 the simulated system provides most favourable performance in terms of power consumption, quality of service and convergence rate.

4.6 Diversity

To analyze the effect of diversity combining on the system performance, we have considered diversity combining of to paths (which differ in path length anywhere between 2% to 10%) having independent, lognormally distributed, shadowing. The power fraction in the two paths, for the graph shown in Fig. 4.18 and Fig.4.19 is taken as 0.7 and 0.3 of the total mobile power.

Fig. 4.18 and Fig. 4.19 depicts the effect of diversity reception on the dropping and blocking probability as a function of traffic load in the system. The performance significantly improves when the diversity is employed. The dropping probability reduces considerably, with the diversity reception, providing better reliability. The blocking probability remains more or less the same upto 11 Erlangs , but blocking for diversity reception gradually increases and exceed that for nondiversity reception case, mainly because of much lower dropping rate with the diversity reception compared to the nondiversity reception case at higher loads.

4.7 Congestion

We have tried to examine the congestion condition in the network through the method of eigen value calculation which has been analyzed mathematically by Hanly [11].

For this we have used the macroscopic quantity, the total received power at a base station, as an element of the link-gain matrix, similar to the one defined for microscopic quantity (mobile transmitted power) by the Eq. 2.10. We calculated the eigen value, for the degenerate case of single cell network. Here, though the eigen value increased with load in the network, but even with extensive runs of the programme we never faced an infeasible power control situation. To analyze an infeasible situation we tried but could not simulate , an infeasible power control situation that could have led to the power warfare. As per analysis done by Hanly [11], the eigen value of the said matrix should approach unity as the system configuration reaches to an infeasible situation, whereas the eigen values obtained through the simulation model were in the range 0.03 to 0.055. So the capability of the power control scheme to handle a power warfare situation could not be tested. The variation of the eigen value for a network running

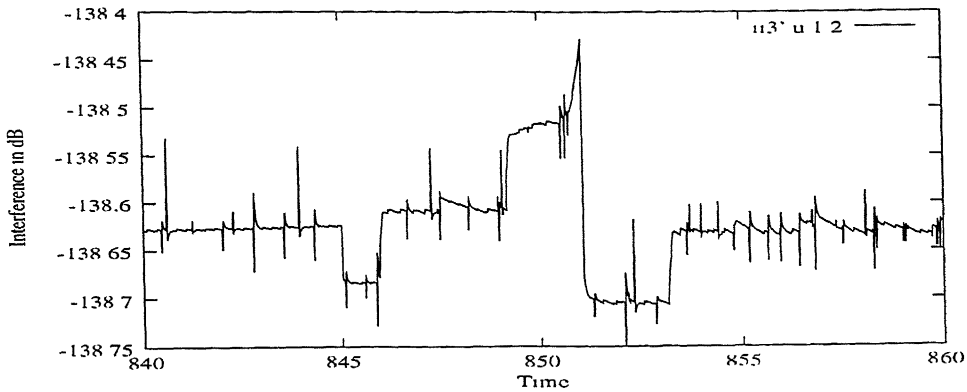

Figure 4.14: Power updation with $\beta = 0.3$

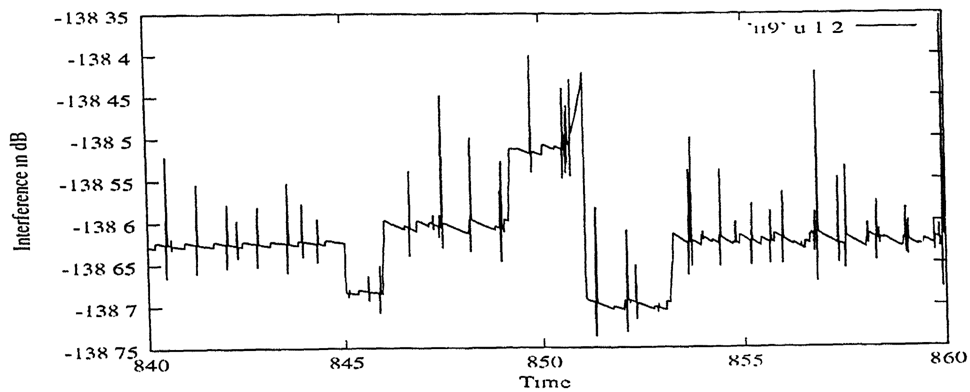

Figure 4.15: Power updation with $\beta = 0.9$

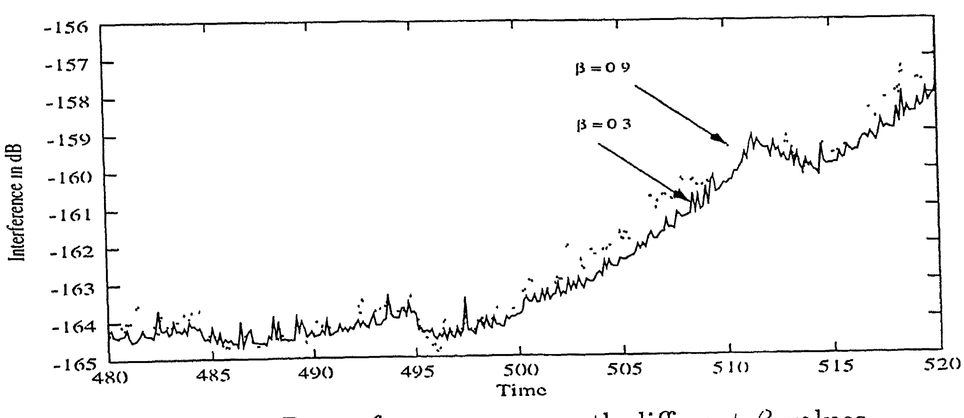

Figure 4.16: Rate of convergence with different β values

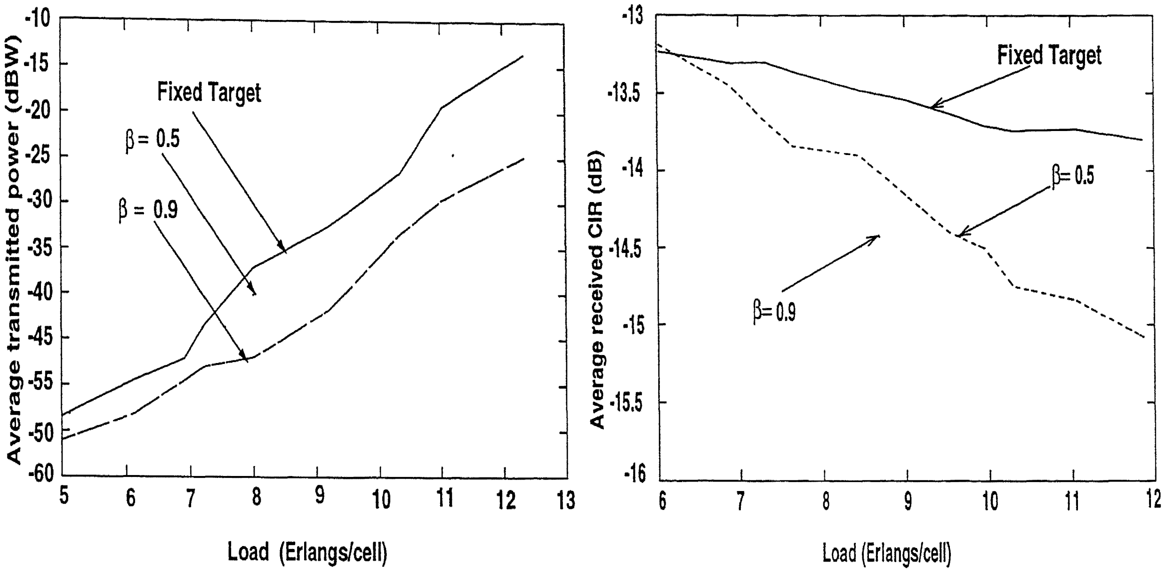

Figure 4.17: a) Effect of β on the average transmitted power b) Effect of β on the average received CIR

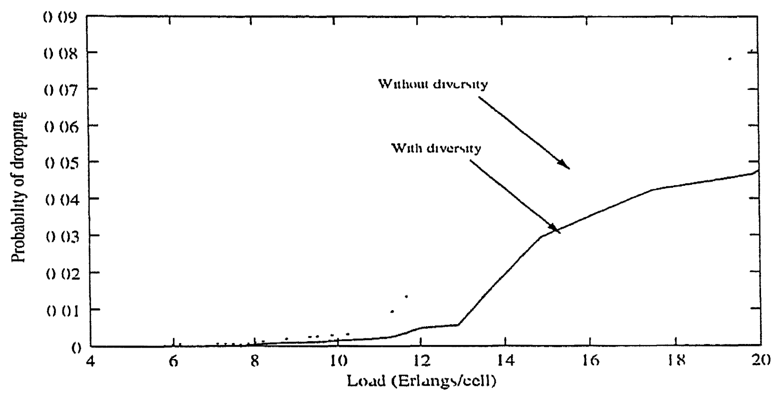

Figure 4.18 Effect of diversity reception on dropping probability

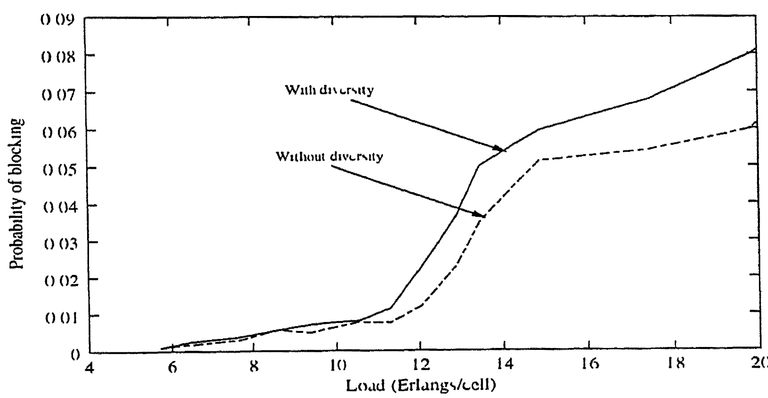

Figure 4.19: Effect of diversity reception on blocking probability

at a constant mean load, though changed with time and the instantaneous load, but the pattern of variation eluded any meaningful conclusion

4.8 Conclusion

The simulation model that has been developed in the present work, provides an efficient tool to examine the dynamic performance of a mobile cellular network. The environment of the network that has been simulated, incorporates all the propagation degradation factors of shadowing, distance losses etc. that can be tackled by a power control scheme with the practical limitations imposed by finite processing time, delay and error in power control command transmission etc..

The improvement in the system performance with the *soft-drop target* power control scheme can be enumerated as :

- The power control scheme is rugged against a wide range of power variations, effectively compensating the *near-far effect.*
- It ensures much higher capacity compared to the *fixed target CIR* power control scheme.
- It guarantees much better system performance in terms of reduced blocking and dropping probabilities (with similar blocking and outage durations) with quite acceptable degradation in link quality.
- The concept of diversity reception has been incorporated which improves further the performance and reliability of the power control scheme.

Also, the simulation model provides a great amount of flexibility, in a sense that, with minor changes in the simulation input parameters the dynamic behaviour of the system can be analyzed for different cell structures, arrival and call (service) duration patterns, multi-data rate services etc. to suit service requirements of the future systems.

4.9 Scope for Future Work

Even though, a system may be simulated, taking into account all the important parameters, there is always scope for making the simulated system more attuned to the practical system constraints. We therefore propose further analysis be made

- to explore the congestion and infeasibility combating capability of the power control scheme
- to analyze its suitability to micro and hetro/hybrid cell structures.
- to test the system performance with different distributions for shadowing, arrival and service patterns, multi channel, multi rate services, non uniform user density etc..

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